BIOMECHANICS OF RUNNING—
Electromyographic Analysis of the Hip during Jogging, Running and Sprinting

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The patterns of muscle action during human locomotion have been investigated for several decades. Lower extremity electromyographic activity in walking was investigated by Bartholomew and the Prosthetic Research Group at Berkeley in 1953. (1) Others investigated the actions of specific muscles during various leg movements. Basmajian and LeBan et al. (6) examined the electromyographic action of the iliopsoas muscle. These studies have led to the investigation of running. Saito et al., (10) presented temporal data on the gait cycle of running. James and Brubaker (5) presented a descriptive analysis of running. Other researchers have directed their work toward sprinting: Fenn (4) investigated frictional and kinetic factors in 1930, and Dillman (3) and Ralph Mann (7) used kinetic analysis. Mann and Hagy (9) and Mann et al. (8) investigated temporal and electromyographic patterns of walking, running and sprinting.

This study investigates and describes the electromyographic activity of the lower extremities and trunk musculature during jogging, running, and sprinting.

Materials and Methods

Subjects of this study were 15 highly trained San Francisco State University varsity trackmen specializing in distances of 100 to 800 meters (age range, 19 to 26 years). The study was conducted at the Gait Analysis Laboratory, Shriners Hospital for Crippled Children, in San Francisco, California using a 35 meter runway. The runners were trained so as to be familiar with the runway, speed of gait, and the apparatus used in trials of jogging at an 8 min/mile pace, three successful trials of running at a 6 min/mile pace, and three successful trials of a sprinting speed of less that 10 sec/100 m. A successful trial was one in which the speed variance was within 10% of the target speed, good quality electromyographic signals were observed, and there was no discernible alteration in velocity within the filming area.

Each runner was filmed from the side by means of two high-speed 16 mm Photosonic (16-1PL) cameras at 200 frames/sec. The filming occurred from the 17th to the 23rd meters of the track. In addition, a 16 mm Hycam camera simultaneously filmed the subject and the electromyographic tracing from a Tectronix RM 561A oscilloscope. The films were viewed on a Vanguard Film Analyzer, and the period of activity for each muscle was ascertained. The electromyographic data were obtained from surface electrodes in the case of superficial muscles. These included the gluteus maximus, the gluteus medius, the tensor fascia lata, the quadriceps, the medial head of the hamstring, the lateral head of the hamstring, the gastrocnemis, the tibialis anterior, and the intrinsic muscles of the foot. Indwelling electrodes consisting of two fine 0.0065 inch enamel-coated copper-wire electrodes with bared tips were implanted in the iliacus, the adductor longus, and the peroneus longus muscles. The iliacus electrode was placed into the iliacus muscles by obliquely inserting a 4-inch needle starting at a point approximately 2 cm medial to the anterior superior iliac spine. The needle which carried the electrodes was angled toward the ilium and came to rest within the iliac fossa. Upon placement of the electrode, the subject performed a specific anatomical movement, e.g., hip flexion, which elicited the appropriate audio and oscilloscopic signals. The runner jogged until an adequate electromyographic signal was obtained on the oscilloscope for satisfactory photography.

The electromyographic data were reduced by an analytic projector with a frame-measuring device. By analyzing the film on a frame-by-frame basis, the electromyographic data could be reduced in order to obtain phasic activity of each muscle at each speed of gait. Once the data were analyzed, the average activity was calculated and used to compare the runners.

The cycle times were recorded in real time by measuring the number of frames for each gait cycle, so that the length of the cycle and its various components could be obtained for each runner at each speed. The data were also represented as percent of the gait cycle in order to permit easier comparison of jogging to running to sprinting.

The cinematographic technique enabled us to obtain the range of motion of the joints in the lower extremities in the sagittal plane. The motions about the hip, knee, and ankle were plotted to understand the relationship between muscle activity and joint motion.

Description of Gait Cycles

To describe the relationship of the electromyographic data to the joint range of motion, we used the description of the running cycle presented by Slocum and James. (11)

Results

Speed of Gait and Cycle Time

The speed of gait is given in Table 1. The cycle time is given in Table 2 (and Figure 1).

TABLE 1
Speed of gait for walking, jogging, running, and sprinting

Activity	Avg. speed of gait (m/sec)	Pace
Walking	1.32	Approx. 20 minute mile
Jogging	3.31	Approx. 8 minute mile
Running	4.77	Approx. 6 minute mile
Sprinting	10.8	9.21 sec/100 m

TABLE 2
Cycle time for walking, jogging, running, and sprinting

Activity	Total cycle time (msec)	Stance phase (msec)
Walking	1000	620
Jogging	800	260
Running	700	220
Sprinting	540	140

Cycle Time

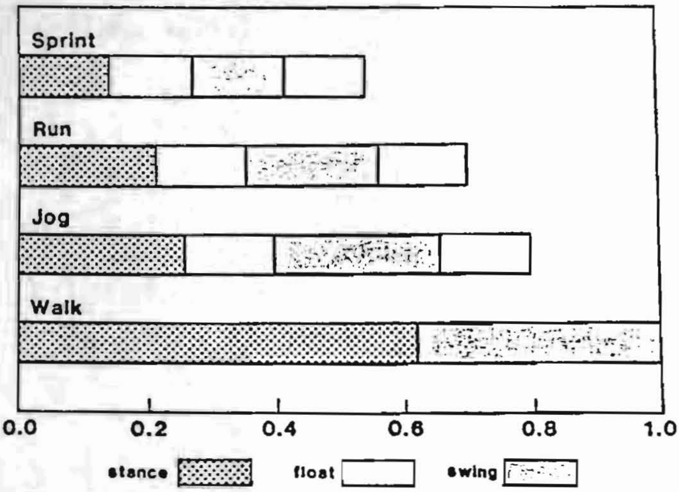


Figure 1. Cycle time. Note that as the speed of gait increased, the stance phase decreased, and conversely the swing and float time increased.

Range of Motion and Electromyographic Data Expressed in Real Time

The hip (Figure 2). As the speed of gait increased, the total range of motion of the hip joint increased, but careful observation of the data reveals that for jogging and sprinting the hip joint extended during support from about 50 to 5 degrees of hyperextension. The degrees of flexion during swing phase increased with the speed of gait to approximately 40 degrees for jogging, 60 degrees for running, and 80 degrees for sprinting. At all speeds, maximum hip extension was reached at or immediately after toe-off, and maximum flexion at about two-thirds of the way through swing phase as contralateral toe-off was occurring.

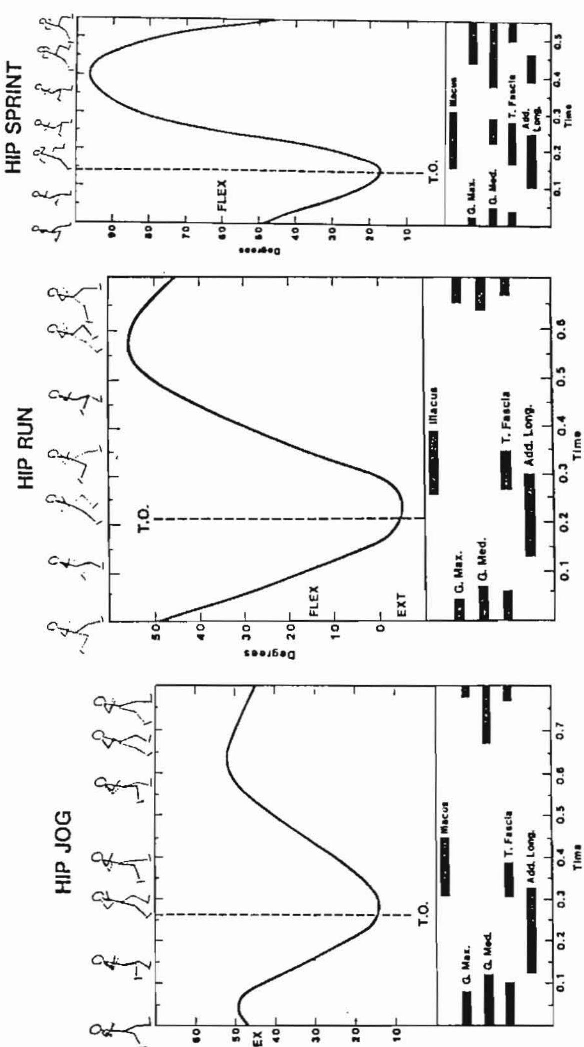


Fig. 2. Range of Motion and Electromyographic Activity about the Hip Joint during Jogging, Running and Sprinting

Relating the degrees of hip flexion to the period of activity of the iliacus demonstrated that about 50% of hip flexion occurred while this muscle was active for jogging and running, but about 90% for sprinting.

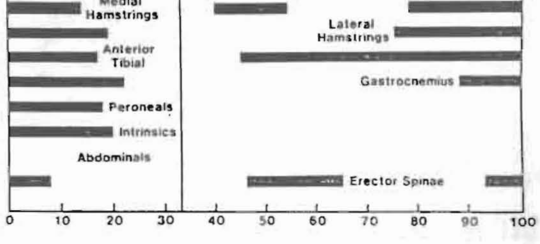
The gluteus maximus, with increasing speed of gait, demonstrated decreased early support activity and increased late swing-phase activity. The gluteus medius and tensor fascia demonstrated decreased early support activity with increasing speed. The period of activity of the adductor longus began just after toe-off and continued into early forward swing. In sprinting there was a second period of activity in the adductor longus during early foot descent.

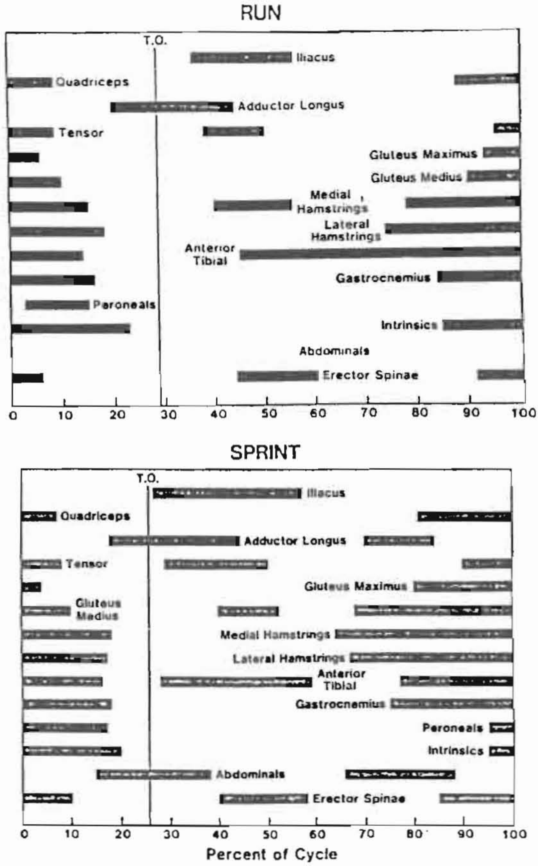
Electromyographic Data

Electromyographic data for jogging, running and sprinting is expressed in percent of cycle in Figure 3. This allows comparison of muscle activity for each speed of gait. The erector spinae muscle group was studied and found to demonstrate the same period of activity for jogging, running, and sprinting, which was from late foot descent and early midsupport, and a period of activity during forward swing. The rectus abdominis muscle was also studied. It did not present any consistent pattern during jogging and running, but was consistently active during the toe-off phase of support and early forward swing.

Fig. 3.

Electromyographic activity during jogging, running, and sprinting. Expressed as percent of cycle.





Discussion

The description of the gait cycle in terms of support phase and swing phase corresponds to specific events presented on the graphs.

In Figure 2, follow-through which begins after toe-off and ends with maximum extension of the hip, is a very short phase, since maximum extension occurs within less than 50 msec after toe-off.

Forward swing begins after follow-through and ends with maximum hip flexion, which occurs about two-thirds of the way through swing phase. Foot descent begins after forward swing and ends with foot contact. This event occurs during the last one-third of swing phase.

Temporal Changes in the Gait Cycle with Increasing Speed

As the speed of gait increased, the total cycle time decreased (Figure 1). The length of time the foot was on the ground, namely the period of support, likewise diminished as the speed of gait increased. Our data show that for jogging the foot was on the ground for 260 msec, or 32.5% of the cycle; for running, 210 msec, or 29.5% of the cycle; and for sprinting, 140 msec, or 26% of the cycle. Compared to an individual who was walking, the support time was reduced considerably, since the person walking at 120 steps/min spent approximately 600 msec for support phase, or 62% of the cycle. Concomitantly, the swing phase increased as the speed of gait increased. The importance of this measurement is that as the support phase decreased from 260 to 140 msec, the range of motion of the hip was increasing. The angular velocity at the hip must also increase significantly, which requires a greater expenditure of energy and force by the body, thereby increasing the possibility for injury.

Electromyographic Data

Looking at the electromyographic data as a whole and expressed as percent of cycle, the sprinting demonstrated a greater amount of electromyographic activity than jogging or running. In real time, however, there was less activity during the support phase as the speed of gait increased, although the swing phase activity increased about the hip during sprinting.

The lack of consistent electromyographic data for the abdominal muscles, except during sprinting, was unexpected. The activity in this muscle during sprinting is probably related to the forward and backward movement of the pelvis in the sagittal plane. The period of activity corresponds to the end of the hip extension when the pelvis is also reaching maximum extension or backward rotation. The abdominals would therefore be undergoing an eccentric contraction. The activity then continues after toe-off, through follow-through, and into early forward swing, during which time flexion of the pelvis and hip are initiated. It is probable that the forward movement of the pelvis just precedes the onset of hip flexion and the pelvis movement is brought about by a concentric contraction of the abdominal muscles. The second period of activity of the abdominis occurs when the opposite extremity is undergoing the same movements.

Joint Range of Motion

As observed in the graphs of joint range of motion (Figure 2), as the speed of gait increased, the magnitude of the motion about the hip, in degrees and in speed of motion, increased considerably. In the hip joint, approximately 80 degrees of motion occurred within 250 msec during sprinting, compared to 37 degrees of motion within 400 msec for jogging. The muscle forces and angular velocity about the joint necessary to produce changes of this magnitude in such a short period of time are extremely great.

Electromyographic Activity Versus Range of Motion

Muscles about joints carry out their activities by a shortening (concentric) contracture or a lengthening (eccentric) contracture. The concentric contracture, as a general rule, produces a rapid joint movement which moves the body forward, e.g., iliacus producing hip flexion and quadriceps producing knee extension. An eccentric contraction, as a general rule, produces a decelerating action, e.g., gluteus maximus decelerating hip extension. Some muscles demonstrate both concentric and eccentric activity, e.g., the quadriceps undergoes a concentric contraction to bring about knee extension during foot descent, and then an eccentric contraction to control knee flexion during foot contact and midsupport.

The iliacus muscle became active immediately after follow-through and remained active for approximately 150 msec during jogging, running, and sprinting. During this period, hip flexion was initiated, so that in jogging approximately 17 degrees of hip flexion out of a total of 37 degrees occurred; in running, 30 degrees out of a total of 58 degrees; and in sprinting, 70 degrees out of 80 degrees. We believe this indicates that the iliacus, along with the psoas, is the prime flexor of the hip joint, and that as the speed of gait increases, it is the activity of this muscle that brings about the greatest change in the movement of the lower extremity in the line of progression. This seems to indicate that in order to increase one's speed further, flexion of the hip is the prime mover, and the remainder of the lower extremity follows. Although knee extension begins secondary to the movement of the hip joint, approximately the last third is brought about by the concentric contraction of the quadriceps.

The gluteus maximus demonstrated increasing activity during foot descent as the speed of gait increased. The function of the gluteus maximus is probably to decelerate the swinging thigh prior to foot contact. Its period of activity during the support phase, however, is just the opposite; namely, there is less activity during sprinting than during jogging. During the beginning of the support phase, the gluteus maximus may be functioning to continue hip extension. The greater period of activity during the support phase of jogging may be related to the fact that hip extension during jogging does not begin until approximately 50 msec into the support phase, whereas during running and sprinting hip extension is already occurring.

The activities of the gluteus medius and tensor fascia demonstrated little change as the speed of gait increased. These muscles provide abductor stability to the hip joint just prior to and after foot contact. At the time of foot contact, the femur in relation to the pelvis is adducted; therefore, these muscles undergo an eccentric contraction, and then throughout the remainder of the support phase, as abduction occurs at the hip joint, they undergo a concentric contraction. The adductor longus demonstrated a greater period of activity during jogging and the least activity during sprinting. At all speeds, it became active during toe-off and remained active during follow-through and early forward swing. During sprinting, there was always a short burst of activity when foot descent began.

Precisely what role this muscle is playing is difficult to state with assurance, although during toe-off a lateral force is being exerted against the stance leg and abduction is occurring at the hip joint as the contralateral hip is reaching maximum flexion. The adductor longus probably acts to stabilize the femur against the pelvis and undergoes an eccentric contraction. The short burst of activity at the beginning of foot descent during sprinting may be to adduct the thigh to bring the foot toward the midline.

The gastrocnemius function, which represented the posterior calf muscles, demonstrated onset of activity during foot descent, probably providing stability to the ankle joint in preparation for foot contact. The activity of the gastrocnemius continued to foot contact and the midsupport phase. During this period of support, rapid dorsiflexion is occurring at the ankle joint, and the gastrocnemius undergoes an eccentric contraction which controls the forward movement of the tibia over the fixed foot. It is this stabilization of the tibia by the gastrocnemius, along with the forward movement of the trunk, that enables the knee to extend during toe-off in jogging and running. The grastocnemius, along with the other posterior calf muscles, then undergoes a concentric contraction which initiates plantar flexion, which begins the toe-off phase of support. In this study the amount of plantar flexion that occurred during the period of activity of the gastrocnemius was surprisingly small. It would appear as though little or no push-off per se is occurring from the posterior calf musculature. It should be noted, however, that during this same period of time the swinging limb, and in particular the hip, is undergoing rapid flexion that reaches its peak just after plantar flexion of the ankle joint begins. It is therefore postulated that the majority of the forward propulsion during jogging, running, and sprinting is brought about by the rapid hip flexion of the swing limb, rather than by push-off of the stance limb.

Intrinsic muscles of the foot demonstrated activity near the end of the foot descent during running and sprinting and during the first two-thirds of the support phase. The intrinsic muscles then became inactive during toe-off when the foot was being unloaded. We believe this further substantiates the lack of push-off by the stance limb.

Summary

This paper demonstrates that as the speed of gait increases, the period of stance progressively diminishes. The most important muscle appears to be the iliacus, which brings about rapid hip flexion which is linked to extension of the knee. The driving force of hip flexion and knee extension, along with the action of the arms, propels the body in the line of progression, rather than push-off from the stance limb per se.

Acknowledgements

The authors thank David E. Fix, Ph.D., Track and Field Coach, Lewis and Clark College, Portland, Oregon, for his help in providing the athletes for this study.

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