# FOOT FUNCTION IN RUNNING: RESEARCHER TO COACH

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The basic form of ambulation used by most people remains walking, but during the past few years, there has been an ever enlarging segment of our population desiring to run. Competitive and recreational running for health and pleasure are common activities engaged in by millions. In addition, running is a basic skill common to many competitive and recreational activities. Consequently, a more thorough understanding of the activity is desirable.

Initially our research program was directed toward a comprehensive study of running as a total body activity. Most of our efforts, however, have been directed toward the functional evaluation of the lower extremity with emphasis on foot function during the support phase. The foot forms the dynamic base upon which the runner functions. The actions that occur at the foot-shoe-surface interface are of critical importance since they influence the functional mechanisms of the entire body and especially the lower extremity. For each mile run, the average runner encounters 450-550 collisions at 2-4 times body weight as the foot impacts the running surface, placing strenuous demands upon the foot and leg.

Due to this obvious stress, considerable emphasis has been given to the importance of protecting the foot during this collision phase of running. Certainly protection is needed. However, until recently considerably less emphasis was given to another equally if not more important function--stabilizing and controlling the foot.

The basis for a major part of our initial research plan came from a clinical study of 232 running injuries done in conjunction with the Orthopedic and Fracture Clinic of Eugene (James et al., 1978). Identified in the study were a number of treatment modalities which were used with varying degrees of success. The treatments used on the injured runners and their frequency of use are summarized in Table 1. The first four, and most often used, of the treatments are related to two primary biomechanical concepts: (1) shock absorption and (2) control and stabilization. Based upon the injury data, these two factors appear to be of about equal importance, although it has been suggested more recently that the latter concept might account for as many as 75 percent of the injuries encountered by runners.

TABLE 1

Treatment Modalities Used for Injured Runners

| Modality | % of Patients |
|---|---|
| Rest | 47 |
| Orthotic Device | 46 |
| Reduced Mileage | 26 |
| Shoe Change/Modification | 19 |
| Steroid Injection | 17 |
| Anti-inflammatory Agent | 14 |
| Surgery | 5 |

In this paper I would like to briefly present a summary of selected research findings in the areas of basic lower extremity function and selected functional relationships.

## EXPERIMENTAL SET-UP

Typically, two experimental set-ups have been used to collect data. One makes use of a heavy duty treadmill and one or two high speed cameras (100-200 pictures/sec) to obtain kinematic data only. The other consists of a force sensitive platform mounted on a frame set into a large block of concrete embedded in the ground flush with the running surface. The plate measures the forces generated by the runner at the foot-shoe-surface interface and feeds the information (500- 1000 points/sec) directly to a small laboratory computer where it is stored for later processing. Two high speed motion picture cameras (100-200 pictures/sec) are usually used in conjunction with this set-up to obtain additional information.

The plate is located in a long runway to provide adequate distance for runners to reach the desired speed necessary for each experiment. To further control the setting an electronic timing system is used to monitor running speed through the critical area.

The data presented are summarized from a series of studies conducted in our laboratory (Bates et al., 1978, 1979a, 1979b, 1980, 1981). Both male and female runners have been evaluated during treadmill and overground running at speeds varying between 2.82 and 4.91 m/sec (5:30 to 9:30 min/mile). In addition, one group of male sprinters (n = 12) was tested at faster speeds of 7.52 to 7.75 m/sec ( $\sim$ 3:30 min/mile).

LOWER EXTREMITY FUNCTION

As a simplified starting point, the support period can be divided into two phases. Three sets of labels for these phases can be used dependent upon the data being examined. When viewing kinematic parameters these phases can be identified as an initial flexion phase followed by an extension phase. On the other hand vertical force data suggest the terms loading and unloading while anterio-posterior force data suggest braking and propulsion as the appropriate terms. In general, the transitions between phases for each of these classification schemes occur at about the same relative time during the support period and are relatively independent of such variables as running speed and type of footfall. The occurrences of these phases and other critical events are summarized in Table 2. Figure 1 contains illustrations of selected events.

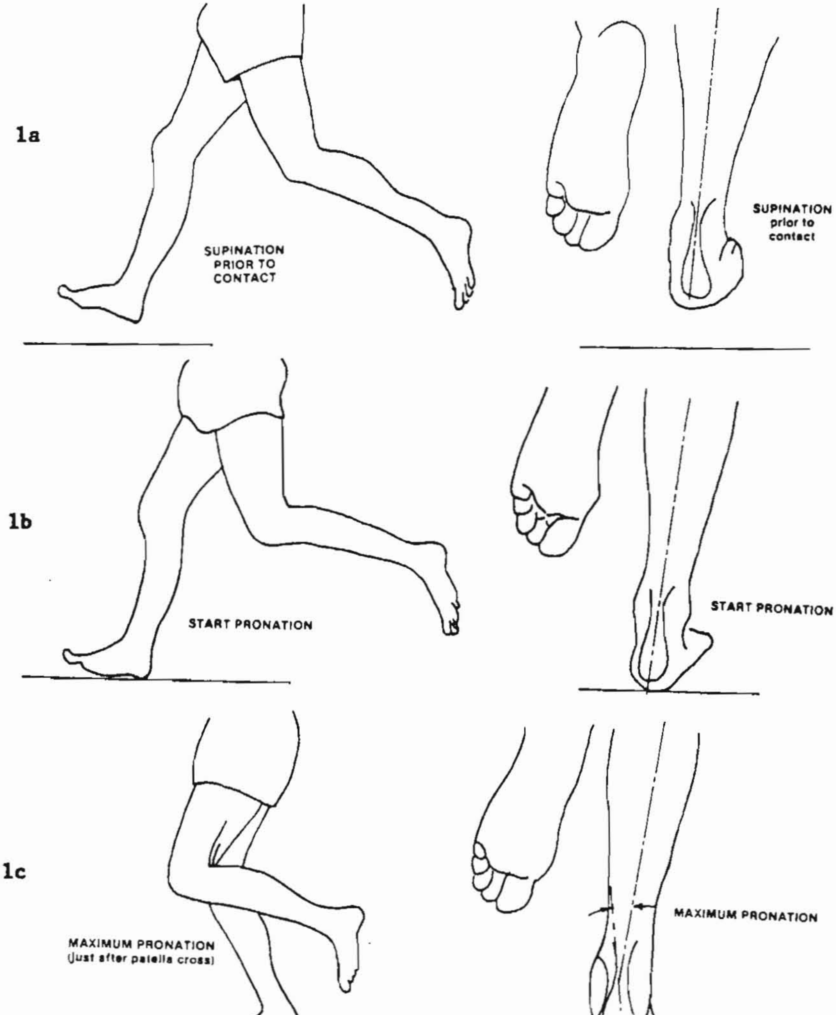
TABLE 2

Typical Range of Values for the Occurrence of Selected Events Within the Support Phase[a]

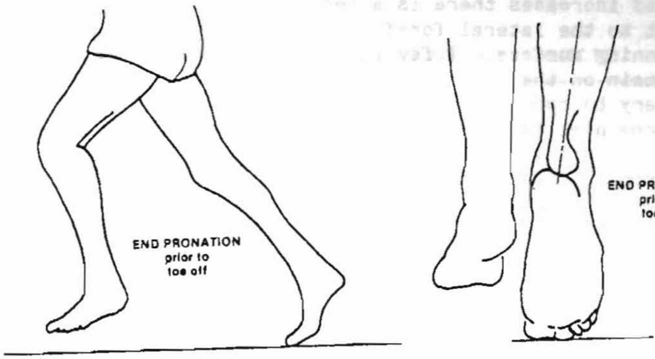
| Event | Percent[b] |
|---|---|
| Foot Strike | 0 |
| Begin Pronation | 5-20 |
| Maximum Impact Force | 8-15 |
| Maximum Pronation | 35-45 |
| Maximum Loading Force | 35-45 |
| Brake/Propel Transition | 35-45 |
| Maximum Knee Flexion | 35-45 |
| Patella Cross | 35-45 |
| Maximum Ankle Dorsiflexion | 50-55 |
| End Pronation | 70-90 |
| Toe Off (Total Support) | 100 |
| Period of Pronation | 55-85 |

[a]All values are taken from Foot Strike

[b]All values computed as a percentage of Total Support


1a
SUPINATION PRIOR TO CONTACT
SUPINATION prior to contact
1b
START PRONATION
START PRONATION
1c
MAXIMUM PRONATION (Just after patella cross)
MAXIMUM PRONATION

1d




1e

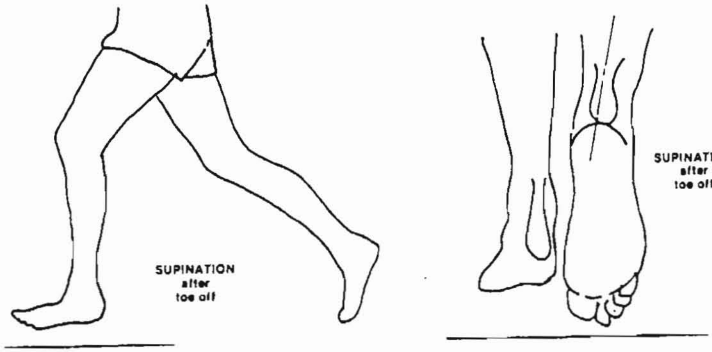



**Figure 1. Lateral and Posterior Views of the Lower Extremity at Selected Positions**

The support phase typically lasts .15 to .25 sec and gets shorter as running speed increases. The transitions indicated above generally occur about 35 to 45 percent through the support period. At slower speeds most runners make contact with the running surface on the lateral side of the heel. As running speed increases there is a tendency for some runners to transfer initial contact to the lateral forefoot, followed by a lowering of the heel to contact the running surface. A few runners make initial forefoot contact and are able to remain on the ball of the foot throughout the entire support period. Contrary to popular belief most skilled runners do not go through a transition from heel to forefoot contact as speed increases, and even most sprinters are not strong enough to remain on the ball of the foot throughout the support period. Of a group of 24 skilled sprinters and distance runners, eight sprinted with a heel-toe footfall pattern while only five were able to maintain a position on the ball of the foot throughout the support period (Mason, 1980).

The description that follows is for a runner who makes initial heel contact, however, the general actions are similar for the other types of footfalls as well although specific actions will be exaggerated or de-emphasized to accommodate each footfall pattern.

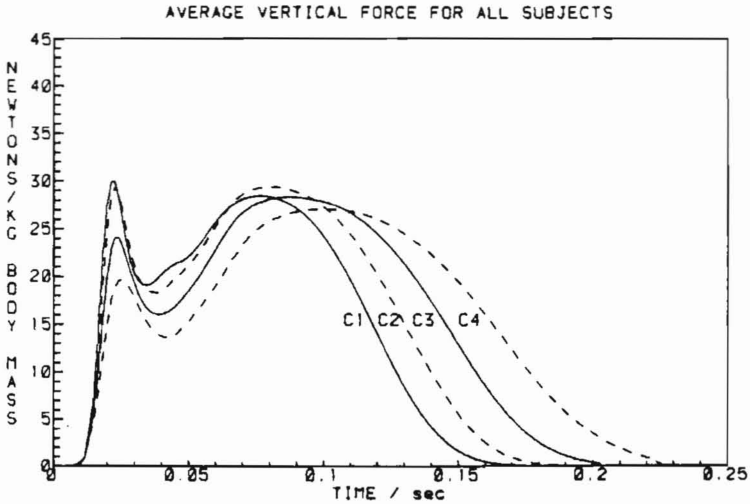
Regardless of the type of footfall the foot will usually be in a slightly supinated position at touchdown (Figure 1a). This would appear to be the natural anatomical result of the swing of the leg toward the line of progression. This movement is a structurally inherent action of the lower extremity and results in a slight plantarflexion of the subtalar joint as well as adduction of the forefoot and inversion of the heel. Functionally this position brings the forefoot closer to the running surface which allows for a greater range of movement in the subtalar joint and consequently a greater time period over which to absorb the initial forces of impact.

Impact results in the foot being forced rapidly onto the running surface and in the initiation of the flexion phase which consists of hip and knee flexion, ankle dorsiflexion and pronation. The heel begins to rotate rather rapidly as the foot-shoe systems adjust to the running surface. Due to the relationship of the knee to the foot in the lateral plane at foot contact the leg is rotated laterally several degrees as a result of the eccentric load and sudden impact but quickly rebounds to its original position.

Figure 1b shows the calcaneous in a neutral position (begin pronation) as the subtalar joint is about to pass from a supinated to a pronated position. This action occurs sometime between heelstrike and 20 percent into the support period depending upon running speed, foot covering and anatomic variations. The occurrence of this event is quite variable.

Maximum pronation occurs between 35 and 45 percent into the support phase as do maximum knee flexion and patella cross (Figure 1c). This is about the same time that the total body center of gravity passes over the base of support. The loading and braking phases terminate at this point and the body begins to propel itself forward into the next airborne phase. During this period of near maximum loading we have observed most runners, including sprinters, to have their feet externally rotated or in a toe-out position regardless of running speed. Observations of the men's and women's 100 m dash finalists in the 1976 U.S. Olympic trials showed 15 of the 16 runners in a fairly exaggerated toe-out position during mid-stance.

2a




2b

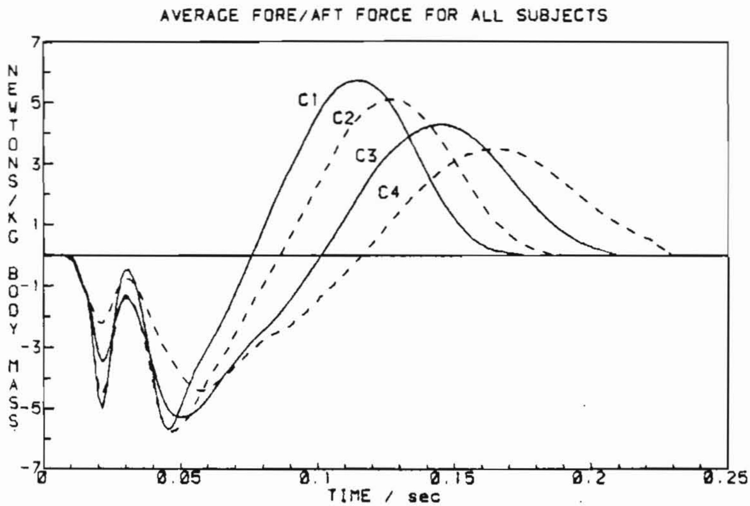
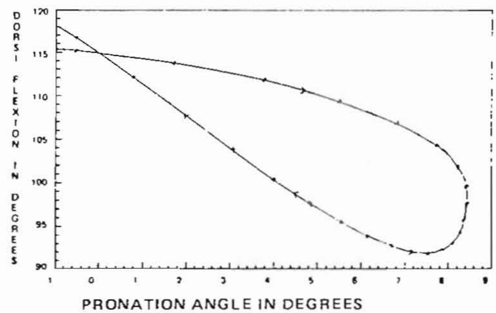



**Figure 2. Average Force Curves for Different Running Speeds**

RELATIONSHIP OF PRONATION TO DORSI FLEXION COMPUTED FROM 33 FOOTFALLS
PRONATION ANGLE (FROM REAR) VERSUS DORSI FLEXION (FROM SIDE)

3a

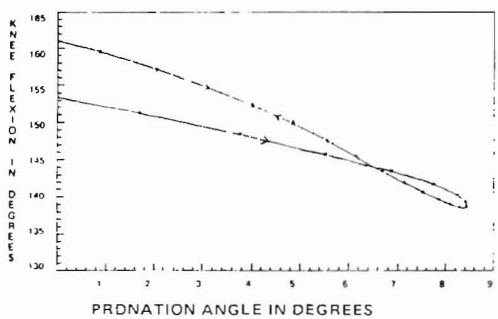



Plus signs mark off equal time intervals.

PARAMETERS COMPUTED FROM 6:00 & 6:15 MINUTE MILE PACE ON THE TREADMILL

RELATIONSHIP OF PRONATION TO KNEE FLEXION COMPUTED FROM 33 FOOTFALLS
PRONATION ANGLE (FROM REAR) VERSUS KNEE FLEXION (FROM SIDE)

3b




Plus signs mark off equal time intervals.

PARAMETERS COMPUTED FROM 6:00 & 6:15 MINUTE MILE PACE ON THE TREADMILL

**Figure 3. Relationships Between Selected Anatomical Components**

The propulsive phase coincides with the extension phase and begins with the large muscles. Both hip and knee extension begin while the ankle joint continues to dorsiflex, thus creating some overlap between the flexion and extension phases. The foot remains in a near maximally pronated position. About 50 to 55 percent into the support phase maximum ankle dorsiflexion occurs. The center of gravity is now forward of the support leg and the propulsive phase has been initiated. The gastrocnemius has been put under stretch and is now ready to begin its contribution to the propulsive phase, its actions being enhanced by the stretch mechanism and reduced load.

The body now begins to move forward more rapidly. The foot begins to supinate (it is still in a pronated position) more rapidly and returns to the neutral position (end pronation) anywhere from 70 to 90 percent through the support phase (Figure 1d). Consequently, the foot is in a pronated position between 55 and 85 percent of the support period. The events of begin and end pronation were found to be the most variable.

The foot now actually assumes a supinated position as the knee continues to extend while the hip hyperextends (Figure 1e). The pushoff position of the foot and ankle is also a structurally inherent position which produces a more rigid foot which helps maximize the final thrust of the support leg.

Graphic displays of the corresponding kinetic phases are shown in Figure 2 for various running speeds. The vertical force curves (Figure 2a) show the loading phase to consist of two parts. There is an initial high speed impact loading followed by a rebound and then a continued loading at a slower rate. The initial impact is a result of the sudden collision between the foot and running surface and is evidenced kinematically by the entire flexion phase but in particular by the rotation of the leg in the lateral plane. Following this impact there is a rebounding or adjusting of the system as evidenced by the force curves and the return of the leg to its original position. These same phenomena are also evident in the anterioposterior force curves (Figure 2b). Upon completion of the loading phase and the transition from braking to propulsion the extension phase begins as the runner regains speed in preparation for pushoff and the next airborne phase.

The effect of increases in running speed upon these data is to increase the magnitude of the initial impact force with very little other change being evidenced (Hamill, 1981; Mason, 1980). For various runners and conditions we have recorded impact values ranging from 1.20 to 2.75 times body weight (BW). At sprint speeds increased values of 2.75 to 3.50 BW have been observed. Maximum load values of 1.35 to 3.52 BW have been documented for all speeds.

The effect of type of footfall on these parameters is more dramatic (Mason, 1980). Mid-foot strikers showed greater impact forces (2.73 BW) at slower speeds than did heel strikers (2.20 BW) but this trend was reversed at the faster speeds (2.80 to 3.27 BW). It was speculated that these differences were related to the point of contact relative to the body center of gravity. At slower speeds the leg positions were similar, resulting in the forefoot being further in front of the center of gravity. At the faster speeds the legs of the forefoot strikers were already pulled back some resulting in a shorter distance to the point of contact. On the other hand, those runners able to stay up on the ball of the foot showed no impact spike at all indicating that the forces were being absorbed by the muscles and connective tissue.

The peak loading forces were generally similar (3.10-3.20 BW) except for the toe runners performing at sprint pace (3.52 BW).

## RELATIONSHIPS AND IMPLICATIONS

Our studies have indicated that functional foot mechanics are quite variable from individual to individual and are very dependent upon anatomical variation as well as the shape, characteristics and fit of the materials placed between the foot and the running surface. Shoes as well as inserts can produce minor but significant functional changes. For example, simply elevating the heel reduces the amount of pronation, which can be further modified by the use of an orthotic insert.

Pronation is a necessary functional mechanism. Pronation allows for the impact forces to be absorbed during a greater time period by the supporting structures reducing the effective magnitude of these forces. Without pronation these forces would have to be even more suddenly and directly absorbed by the supporting structures, quickly causing problems associated with excessive stress.

The relationship between pronation/supination and knee flexion/extension is also important (Figure 3a). Associated with the actions of both of these joints is an obligatory tibial rotation. Pronation and knee flexion are both accompanied by internal tibial rotation while supination and knee extension both result in external rotation. It therefore becomes very critical, especially for people doing a lot of running, that these joint activities be synchronous and complementary. If maximum pronation and maximum knee flexion do not occur at the same time then the two joints will be functionally antagonistic. If this antagonistic period is prolonged, irritations will result in one of the joints, usually the knee.

Figure 3b shows the relationship between pronation/supination and ankle angle. In contrast to Figure 3a where both maximum values occur simultaneously, the ankle attains its maximum value of dorsiflexion significantly later than maximum pronation. This aspect was previously discussed. There is a strong interactive relationship between these two variables. The effect of a shoe with a slightly positive heel will reduce both the period and amount of pronation as well as the amount of maximum ankle dorsiflexion. About 75 percent of the reduction in dorsiflexion is accounted for simply by the modified geometry of the condition. Finally, individuals who lack ankle flexibility due to tight gastrocnemius musculature will often attempt to gain some additional range of movement by flexing more at the knee. If this does not produce adequate results, and it often does not, they are forced to pronate more as a further compensating mechanism.

In summary, I have tried to present some of our research findings in a more general form in hopes that the information will be helpful to others interested in better understanding foot function. Also, several implications regarding foot function and running injuries were discussed. This discussion was not intended to be all inclusive, but was presented to provide some insight into the types of problems we are investigating.

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