# SIGNS OF THE TIMES IN SPORTS BIOMECHANICS

Doris I. Miller
Department of Kinesiology DX-10
University of Washington
Seattle, WA 98195 U.S.A.

Looking back over the past 10-15 years of sport biomechanics, we can see periods of emphasis (and indeed overemphasis) on: instrumentation (cameras, force plates, computers); methodology (three dimensional analysis, modelling, data smoothing, on-line data collection); and subsequently, techniques of conveying information (angle diagrams, computer generated stick figures, vector diagrams). Until the latter part of the 1970's, there were few consistent contributors to the body of knowledge and both the number and scope of publications reflected this situation. Now, however, with appropriate instrumentation, methodology and techniques as well as individuals devoted to the research endeavor, we should be able to make research contributions in sport biomechanics in a more meaningful way than we have in the past.

## RUNNING AS THE BAROMETER OF SPORT BIOMECHANICS RESEARCH

In 1977, I was asked to address a similar topic at the inaugural meeting of the American Society of Biomechanics. What was the state of the art in sport biomechanics? Where was the field going? At that time, I chose to focus upon running and I maintain that there continue to be important reasons for selecting this particular activity as the barometer of sport biomechanics research. These include its long history of scientific investigation; the number of people who could potentially be affected by the results of such research; and the extensive number of biomechanics researchers who, at some time or other, have studied the biomechanics of running. It follows that the most funding, the largest volume of data, and the greatest number of research reports and publications have been devoted to this aspect of sport biomechanics. Likewise, state of the art instrumentation and methodology have been applied in attempting to answer research questions of varying complexity from almost purely theoretical to virtually entirely applied. In addition, we share this area of inquiry with other sport science disciplines. Thus, there are substantial opportunities for cooperative projects with applications in education, medicine, business and industry. Given these facts, few would argue that research in running biomechanics represents a viable microcosm of the field in general.

In my concluding remarks to the American Society of Biomechanics, I indicated that we had a reasonably good understanding of the temporal relationships and linear kinematics of the running stride. Information was beginning to accumulate on the angular kinematics of the segments. Some work had focused upon ground reaction force-time histories and resultant muscle torques. To that point in time, analysis had been limited almost entirely to the sagittal plane (Miller, 1978).

Table 1. Classification of running biomechanics research published since 1977.

| Category | Subcategories | | |
|---|---|---|---|
| Subjects | male | | joggers |
| | female | | distance runners |
| | children | | elite athletes |
| | atypical | | marathoners |
| Conditions | level | grade | curves |
| | treadmill | | overground |
| | | fatigue | |
| | steady speed | | accelerated |
| | competition | practice | laboratory |
| Analysis | | temporal and stride characteristics | |
| | | joint kinematics | |
| | | work - energy - power | |
| | | efficiency | |
| | | ground reaction force | |
| | | muscle activity and resultant torque | |
| Instrumentation / Methodology | | three dimensional analysis | |
| | | electromyography | |
| | | cinematography | |
| | | pressure transducers | |
| | | force platforms | |
| | | treadmills | |
| | | modelling | |

Now a little more than six years later, I have the opportunity to again examine some of the progress that has been made in running biomechanics. Most of the publications since 1977 fall into one of the categories shown in Table 1. As indicated by the extensive (but not exhaustive) reference list, the sheer volume of literature published in the last six years on this one aspect of sport biomechanics is, in itself, impressive and reflects the vitality of the field. It necessitates, however, an even further narrowing of the topic to focus on only one facet of running biomechanics. Of the many examples which could be selected, the ground-shoe-foot interface provides a reasonable topic to represent progress in the field.

## GETTING TO THE BOTTOM OF RUNNING

This area of study begins with the somewhat dated question of how the runner's foot contacts the ground; incorporates force plates and pressure transducers to gain insight into the nature and distribution of the force involved; moves from side to rear-view cinematography to get a better look at the phenomenon; and is proceding to musculo-skeletal models of the effect of repetitive impulsive loading. It has application to shoe design and injury reduction. You may or may not agree that it has implications for directly affecting running technique but its potential for reducing the incidence of overuse injuries may influence the training mileage of both the weekend jogger and Olympic contender.

### How does the runner's foot contact the ground?

Heel first? Initially on the ball of the foot followed by heel contact? Only on the ball of the foot? With the entire foot? And the answer seems to be 'yes, all of the above'.

Common misconceptions held several years ago that individuals either ran completely on their toes or always planted heel first were exposed by Nett (1964) who filmed top runners at 64 fps during competitive events varying in length from 100 m to the marathon. He concluded that initial contact was always made with the lateral border of the foot, a fact which has since been replicated many times (e.g., Cavanagh & Lafortune, 1980; Payne, 1983; Plagenhoef, 1979, 1980; Roche, 1972) and about which there is little or no argument. Nett further concluded that the initial point of contact of the foot with the ground was related to running speed. In the 100 and 200 m distances, it was made high on the ball of the foot, termed by Nett as an active or dynamic foot plant. In the 400 m, it was back a little closer to the heel. In the 800 m, the foot was nearly flat (a metatarsal plant), whereas in distances greater than 1500 m, initial contact was between the heel and the base of the metatarsals (passive or static plant). Regardless of where the contact occurred, Nett believed that the heel touched the ground at some point during stance and that the type of foot plant was related to an energy conservation mechanism.

For the next few years, therefore, it was assumed that initial contact with the ground was related to speed, with foot plant moving forward from the heel to the ball of the foot as the runner progressed from a jog to a sprint. Further research proved this concept overly simplistic. While the general pattern described by Nett has been shown to hold in some cases (e.g., Plagenhoef, 1979, 1980), individuals also have been observed to contact the ground in different ways at comparable speeds (Cavanagh & Lafortune, 1980; Payne, 1983) and, there is evidence to suggest that some individuals retain the same contact pattern over a range of speeds (Hamill et al., 1983; Mason, 1980; Roche, 1972). This research is based not only upon side view films taken at frame rates ranging from 25 fps (Payne, 1983) to 500 fps (Plagenhoef, 1980) but also upon center of pressure records determined from force platform output.

Cavanagh has been instrumental in classifying runners as rearfoot, midfoot, and forefoot strikers depending upon under which third of the foot the center of pressure path begins. Since center of pressure represents the resultant point of application of the ground reaction force, it cannot be used interchangeably with the point of contact. It is safe to assume, however, that rearfoot and forefoot center of pressure paths coincide with initial contacts in corresponding regions of the foot. Midfoot strike patterns, on the other hand, may be indicative of either a midfoot or nearly flat initial foot contact.

It is clear from the research that foot plant patterns, other than being initiated on the lateral border of the foot, are subject to individual variability. Is it true that some individuals are just naturally heel strikers and others, midfoot strikers at all speeds? Or are we simply looking at heel-striking distance runners and mid- to forefoot-striking sprinters using their trained, and thus preferred footfall pattern, across, what is for them, a noncompetitive range of speeds?

In any case, it is necessary to elevate data on foot plant from the basically descriptive level to one which has more theoretical and clinical significance. Two different approaches, one kinetic and the other kinematic, have been pursued concurrently in an attempt to accomplish this end.

## What is the nature of the force experienced by the foot during stance?

In recent years, the force platform has been commonly used to measure ground reaction force during running stance. It provides three-dimensional data and is not nearly as labor-intensive as photoinstrumentation. It is not without its drawbacks, however. Its usually small size necessitates that extra care be taken to ensure that "normal" stance periods are recorded. In some cases, force plaforms have to be located in somewhat restrictive laboratory settings which limit running speeds to moderately slow paces. In addition, fluctuations in the base line as the result of noise related to force platform design or mounting require that a trigger level be exceeded before data are stored or considered signal. We have found that stance time is increased by almost 20 ms simply by lowering the trigger level from 50 to 16 N. Problems related to intersubject comparisons have been effectively dealt with by normalizing forces with respect to body weight and, when appropriate, times with respect to total stance time. Over the past six years, despite some limitations, this kinetic approach has furnished considerable ground reaction data during stance providing a reasonable basis upon which to make observations and draw some conclusions regarding performance.

Although some variability exists among individuals, two general vertical ground reaction configurations have been reported. The first lacks a distinct initial peak and seems to be characteristic of midfoot and forefoot strikers. The second has two peaks and has been identified with heel strikers by several researchers (Cavanagh & Lafortune, 1980; Hamill et al., 1983; Payne, 1983). These two peaks, which have sometimes been referred to as impact and thrust maxima, have been identified by Nigg et al. (1981) as passive (high frequency) and active (low frequency) peaks. They commented that the first or passive peak is controlled only to a small degree by the muscular system. While the statement seems reasonable, their rationale based on the 30 ms or so delay between muscle activation and the generation of force does not seem plausible given electromyographic evidence that the leg muscles are activated prior to, and in anticipation of, foot contact (Elliott & Blanksby, 1979a,b; Mann & Hagy, 1979; Schwab et al., 1983).

A double peaked or bimodal braking pattern has been associated with midfoot strikers (Cavanagh & Lafortune, 1980) while the data of Payne (1983) and Hamill et al. (1983) clearly show its existence also in the data of rearfoot strikers. It is logical to expect that an initial force peak, if present, would be evident not only in the vertical component but the horizontal as well. Timewise, the initial vertical maximum corresponds to the first of the two braking peaks observed.

The smallest ground reaction force component, and also the one which exhibits the greatest inter- and intra-individual variability, is in the medial-lateral direction. Considering that whether medial reaction has a positive or a negative sign depends on whether it is a right or left footstrike as well as the direction of the run across the platform, particular care must be taken in combining these data for analysis. Few, if any, published reports clearly differentiate between the medial and lateral reaction force directions.

Having a reasonable understanding of the ground reaction patterns during running stance and as a function of running speed (Hamill et al., 1983; Roy, 1981, 1982), it is natural to want to relate specific characteristics of the curve to actual performance. While the vertical ground reaction magnitude undoubtedly provides an indication of the degree of attenuation of the landing shock, attempts to associate critical points on the force curve with foot position variables have been generally unsuccessful. However, since ground reaction force reflects the acceleration of the center of gravity of the body, it is little wonder that differences in ground reaction variables as a function of shoe or orthotic type have been less than convincing (e.g., Bates et al., 1981, 1983; Hamill et al., 1983; Norman, 1980). These factors represent but a few pebbles on the beach of variability which characterizes the ground reaction force-time history. A second problem entails trying to infer position changes directly from the force records when, in fact, a double integration would be required to obtain that type of information.

## Foot Plant - Another Perspective

The inability to link ground reaction data to foot function to the extent desired has forced us back to a direct analysis of the foot kinematics. To more clearly visualize the intricate motion of the foot, a camera is positioned behind the subject and a treadmill is commonly employed to ensure a series of footfalls within the field of view. Bates was among the first to extensively use this treadmill-rear camera protocol. We have also found it useful to include a mirror to provide a second view on the same film frame.

Films obtained with this method show the movement of the calcaneus relative to the long axis of the shank and elucidate the mechanism of pronation which ostensibly contributes to attenuating landing shock by extending the contact time and spreading the contact force. Pronation is a complex triplanar movement involving dorsiflexion of the ankle, abduction of the forefoot, and eversion of the calcaneus. Because eversion of the calcaneus with respect to the long axis of the shank is associated with abduction and dorsiflexion during stance, monitoring eversion of the calcaneus provides information on the extent of pronation (Clarke et al., 1983).

Plagenhoef (1980) has indicated that the faster the running speed, the higher the ground reaction force (a fact supported by the results of Roy (1981, 1982) and Hamill et al. (1983)) and hence, the more shock absorption needed. He, therefore, reasoned that the faster an individual ran, the more supinated the foot would be at initial ground contact increasing the potential range of pronation. In general, it has been found that following initial foot contact in a supinated position (i.e., on the lateral border), the foot rolls inward or pronates reaching a point of maximum pronation. It then begins to supinate and continues supination for the remainder of stance. Based on the research of Bates et al. (1979), the following sequence of events can be identified during these two periods of motion:

(1) pronation
    (a) the foot contacts the ground in a supinated position
    (b) the calcaneus passes through a neutral position with respect to the long axis of the shank as it moves from a supinated to a pronated position
    (c) maximum pronation occurs approximately within 30-45% of stance (maximum knee flexion is closely associated with this event).
(2) supination
    (a) maximum dorsiflexion of the ankle occurs about 50% stance time, shortly after maximum pronation
    (b) the calcaneus again passes through a neutral position but this time moving from a pronated to a supinated position
    (c) toe off occurs ending stance.

While a certain amount of pronation is necessary and desirable, excessive pronation may result in injury. Although hard data are generally lacking, excessive pronation has been linked with foot, ankle, knee and hip problems. The question then logically arises as to how the amount and rate of pronation can be controlled or modified. A recent definitive paper by Clarke, Frederick and Hamill (1983) in Medicine and Science in Sports and Exercise has clarified the influence of shoe heel height, heel flare and midsole hardness on rear-foot control. In a well designed and carefully controlled study, they showed that the greatest amount of pronation was associated with shoes which had no medial heel flare and a soft midsole while the least amount of pronation was permitted by shoes with a 30 deg heel flare and a hard midsole. Other studies have linked soft and hard orthotics with reduction in the extent of pronation (Bates et al., 1979; Rogers & LeVeau, 1982).

## CURRENT AND FUTURE DIRECTIONS

While additional comments could be made concerning this particular area of study, sufficient information has been provided to lay the foundation for drawing implications for future directions in sport biomechanics. It seems logical to assume that the past and the present hold the key to the future. It is unlikely that we will completely change direction in the next decade. Rather, we will probably continue to develop and expand areas of research in which we are already engaged.

Both in running and other types of sport biomechanics research, we have proceeded to answer a series of questions. (1) What is happening? We are reaching the point in many areas of being able to pull together research results in a meaningful way. We are getting beyond the stage of having only isolated bits of information bearing little or no relationship to one another. We are passing from a purely descriptive level to one in which specific questions regarding functional and clinical significance are being addressed. (2) Why is it happening? While there is still considerable room for improvement in moving toward a more theory-based approach to our research, we are now ready to address, more often and in greater depth than in the past, the next question in the series. (3) How can we change technique, equipment or execution requirements to improve sport skill performance and to reduce the incidence and/or severity of injury to participants?

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