BIOMECHANICAL RELATIONSHIPS IN DISTANCE RUNNING

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Dr. Keith Williams of UC Davis has been performing biomechanical studies on elite distance runners. Thefollowing was presented at the recent TAC Sports Science Seminar in Colorado Springs. As the author does an excellent job of introducing the material, the editor will say little more except to once again note the emphasis on individual characteristics.

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The following is a summary of information derived from quantitative research studies of elite and well trained distance runners. It does *not* summarize the current state of knowledge resulting from a statistical analysis of research data. Instead, it is a description of relationships involving biomechanical aspects of running which are derived from distance running research by the author and others over the last twelve years. All of the relationships suggested have a quantitative basis, but some elements of intuition and logic have been mixed in. Some of the relationships may be shown to be incorrect or in need of modification in the future, but they should provide some general guidelines for application to distance runners. None of the suggestions should be taken to be globally applying to all runners, because there are numerous individual exceptions. The intent is not to explore the topics in detail, as each could merit a lengthy discussion, but merely to introduce some of the concepts that might be of interest to coaches and runners. Many of the relationships will be nothing new to coaches, but they all do have some conceptual basis based on research findings. Comments, criticisms, and other insights or suggestions are welcomed by the author.

RELATIONSHIPS WITH OVERUSE INJURIES

Impact-Related Injuries: There are a number of runners who have markedly higher-than-average ground reaction forces during the time the foot is in contact with the ground. These athletes are probably at more risk of developing injuries related to loading stress such as stress fractures, plantar fasciitis, shin splints, etc. Often there are no easily recognizable features of their running mechanics that would indicate that they run with high forces. In general we have found that

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Paul Gompers at the 1988 Cross Country Trials.

forefoot and midfoot strikers tend to have slightly higher forces on average than do rearfoot strikers, though there are numerous individual exceptions. Particularly susceptible to these types of injuries seem to be middle distance runners who land in the forefoot. Interval training in shoes with little or no shock absorption may increase loads on the lower extremity to levels that lead to greater injury susceptibility. It is also likely that there are features of lower extremity structure and/or running style that predispose a runner to high forces and greater injury risk. The best way to prevent impact- related injuries is probably to use sound judgment while increasing training intensity and to use good footwear. Runners who do have high impact force levels or a history of impact-related problems should use shoes with good shock absorption characteristics.

Pronation-Related Injuries. Overpronation has received a lot of attention from coaches, runners, clinicians, and footwear manufacturers. There are a large number of individuals who have injuries related to overpronation, such as chondromalacia, other knee pain, plantar fasciitis, etc, but there are also individuals who overpronate who have never had any problems. Overpronation may increase the likelihood of injury, but it does not guarantee that injury will occur. Limited pronation can also be a problem. A moderate amount of pronation is beneficial to the runner because it aids in shock absorption. With limited pronation other tissues (or shoes) must take over some of the shock attenuation needs, and this may lead to other stress-related injuries.

Many of the problems associated with over- or underpronation are due to structural anomalies in the foot and lower leg. Flat feet often show greater pronation (though not always), and rigid high-arched feet often pronate very little. A history of pronation related injuries might help identify individuals with such problems, as could biomechanical testing or clinical examination. Extremes can often be identified visually by carefully watching the running movements from the rear.

Individuals with pronation-related problems can often be helped by appropriately prescribed (by orthopedists or podiatrists) orthotics or by using footwear with effective rearfoot control properties. Overpronators want a shoe with features that effectively control motion, while those with limited pronation would not want such features and instead should get a shoe with good shock absorption capabilities.

Overpronation is sometimes caused by crossing the foot over a midline of the run. When the foot lands across a midline the foot must pronate more in order to get flat. Running with a slightly wider foot strike pattern will reduce the amount of pronation and might relieve some symptoms in a runner who crosses over excessively.

Muscle Strains: While muscle strains are usually caused by doing more “work” than the body can safely withstand, there are probably musculoskeletal features that interact with errors in training causing a strain. Poor flexibility is likely to increase the chance of muscle strains, and muscle imbalances might cause an individual to work at an intensity that stresses the weaker side. Often there are limitations to movements or asymmetries in running mechanics caused by flexibility problems or muscle imbalances. For example, limited hamstring flexibility can lead to less flexion at the hip during running and result in lower than usual knee lift. Or weaker hamstrings on one side of the body might cause less extension on that side and lead to uneven stresses in the hip region. When movements are limited by flexibility constraints, muscles and other tissues must take on loads that they may not be prepared for. Particular attention should be taken when returning to running after a layoff due to an injury

Mechanism of Injury: Overuse injuries occur when the body is subjected to repeated levels of stress that are greater than the body can sustain. A hard workout breaks down various tissues at the microscopic level and the body responds by building stronger tissue if given adequate time to do so. Knowing the appropriate time needed is the difficult part. If degradation occurs at a rate faster than the body can rebuild, an overuse injury may result. Training too hard too soon can result in injury, whether it be at the beginning of the season when the runner is not in good shape, or at the end of the season when at peak fitness. The challenge for the coach is to be able to perceive how to balance intensity and rest for a given athlete.

RELATIONSHIPS WITH PERFORMANCE

At this time I would say there are no features of running mechanics that can be said to be the trademark of the top level performers. Elite runners show a diversity of running styles that is as great as is found in lower level competitors. No one running style seems to be best in relation to performance.

The style that is best for a runner is probably dictated by functional and structural characteristics. Strength, flexibility, size, joint structure, muscle characteristics, and many other factors all interact to influence which style is best for a given runner.

At the same time there are numerous mechanical principles that should not be violated by runners. For example, running with vertical oscillation above a certain level is detrimental to performance because of the work that must be done against gravity. A coach with a runner showing excessive vertical movements should probably work at reducing them, but that does not mean that the lower the vertical oscillation, the better. At some point the benefits from lowered vertical movements are countered by adverse limitations to other movements. Thus, while some general features of good mechanics might be identified and used for guidelines, specific application to an individual must also take into account many other factors.

RELATIONSHIPS WITH FOOTWEAR

Oxygen Consumption: There can be small, but potentially significant, differences in energy costs during
running in different types of shoes. The mechanism of such benefits is not understood well at present, but it is likely to be related to altering the patterns of muscular activity in such a way that less oxygen is needed. This would likely involve changes in movement patterns of the body segments, but such changes have not been explicitly identified as yet.

Typically the differences in energy costs are not greater than 1-2%, though that can be a meaningful difference to the runner. For example, lower energy costs have been associated with lower shoe weight and with good cushioning properties.

Running shoes today have a multitude of features that may influence metabolic energy costs, and it is very difficult to assess how a given shoe will interact without extensive testing. Lightweight racing shoes are likely to have associated lower energy costs, but such benefits must be balanced against the probable increased risks due to running in shoes with typically less shock absorption and motion control.

Ground Reaction Forces: The shock absorbing capabilities of shoes can be influenced by both the design and materials used in construction. Air, EVA, and polyurethane materials can all be equally effective when appropriate design criteria are used. Differences in ground reaction forces can be seen between types of shoes. While these differences are typically small, in the range of 1-5%, they may be important to the runner. A lack of quantitative data concerning the properties of commercially available shoes makes it difficult to objectively identify how a shoe will influence force levels. The consumers are usually left basing their choices on qualitative information, anecdotal experiences, or advertising claims.

Motion Control Features: The design and materials used in shoe construction can influence the ability of the shoe to control movement in the rearfoot and forefoot. Again, a lack of quantitative information makes it difficult to associate specific shoes with certain properties. Differences between shoes are typically not large, in the range of 1-2 degrees, but even these small differences may alter stress distribution in the lower extremity in a beneficial (or detrimental) manner. Features such as rigid heel counters, external counters, firm material under the medial side of the shoe, and other similar features do seem to contribute

Peter Koech (#18), the steeplechase World Record holder from Kenya, competes well on both track and road.

to better motion control. Equally important is how well the shoe fits the runner's foot, and runners should try several brands.

RELATIONSHIPS WITH FOOT AND LOWER LEG STRUCTURE

Foot Structure: As previously mentioned, features of running style such as pronation are influenced by foot structure. A rough assessment of flat vs. normal vs. high-arched feet can be obtained by looking at a barefoot print. Assessing whether the foot is flexible or rigid is more difficult and usually it is wise to involve a clinician if previous injury history indicates possible structural influences on injury. Bowed legs will increase the amount of pronation that occurs and may also alter stresses at the knee and hip. Knock-knees can also affect knee stresses and often influences the movement patterns of the legs, particularly during and following toe-off. Knowledge of structural features of the lower extremity can often help to identify why a runner moves in a particular way and might suggest changes that might be made to relieve stress to the tissues.

Leg Length Differences: Substantial differences in leg length (for discussion purposes, say, greater than one centimeter) occur in a limited number of runners. Most do not have any associated problems, which probably means they have adapted to the difference through some structural or functional means. For example, sometimes the long leg shows greater pronation than does the short leg, and the increased pronation serves to effectively "shorten" the longer leg.

It is usually not easy to see any influence on running mechanics due to a short leg. Since only one leg is in contact with the ground at a time, the other leg may not "know" that it is shorter or longer. Walking would be a different situation since both legs are on the ground at times, and the body may have adapted to this in a manner which would affect running.

When there are associated problems, a heel lift will often help, though a very small height should be initially introduced with gradual increments over a period of time to allow the body time to adapt to the altered stress distributions. Orthotics are another, more expensive, option. A runner with a leg length difference but no related problems may develop some over a period of years as training intensity is increased or other injuries alter stress levels within the body.

Foot Length: Differences in foot length are not common but also not extremely unusual. While there is not a direct influence on mechanics, care should be taken to fit the longer foot to a shoe and use an insert to take up space in the roomier shoe.

Orthotic Devices: Prescription orthotic devices obtained from an orthopedist or podiatrist make the difference of being able to run or not being able to run for many runners. They are cast to conform to the foot and include supporting material on the undersurface of the orthotic that reorients the foot into a mechanically more sound position, ideally relieving stresses that may have led to injuries. Often the differences in pronation associated with the use of orthotics is very small (a half degree to one degree), but the changes to stress levels must be sufficiently large since many runners have been helped by them. Orthotics will not help every runner who has lower extremity problems, and they are expensive, but they can provide relief not obtainable through any other means.

RELATIONSHIPS WITH OXYGEN CONSUMPTION

Individual Differences: There is good evidence that running mechanics can influence energy consumption during running. Unfortunately, there do not appear to be many relationships that can be applied to the majority of individuals. Rather, there is likely to be a set of mechanical features that is optimal for a given individual, and those features will be different from the ones optimal for another individual. Some of the general indications are identified below. A goal should be to work on fine tuning the mechanics of a given runner in relation to that runner's body size, structure, strength, flexibility and muscle characteristics rather than trying to make all runners fit an idealized model.

Kinematics: To date, weak-to-moderate correlations have been found between measures of body movements (kinematics) and oxygen consumption. There is some indication that lower metabolic costs are associated with greater extension of the lower extremity during the toe-off phase. There is also some evidence associating rearfoot landing patterns with lower energy costs, though many individual exceptions are found. At faster speeds of running these relationships may not apply since few runners continue to land on the rear of the foot. Though there is not strong supporting scientific evidence at this time, it is logical that greater energy cost would be associated with runners with excessive vertical oscillation, or with runners who show large decreases in forward velocity following footstrike, necessitating a similar magnitude increase during the push-off phase.

Stride Length: Studies have suggested that most runners will find their most efficient stride length through a self- optimization process. There will still be some runners who can lower energy costs by slight modifications to stride length. My perception is that most of these individuals are overstriding compared to understriding. Particularly susceptible might be shorter runners who run at stride lengths that are long relative to their leg length.

RELATIONSHIPS WITH FATIGUE

Changes in Kinematics: Some kinematic measures seem to change with speed. For example, stride length tends to lengthen, and runners usually flex the knee more during the swing phase as they get fatigued. What is unknown at this time is whether such changes are beneficial or detrimental. Is the change in movement patterns a consequence of not being able to maintain usual muscle activation patterns resulting in a less efficient style? Or do the altered movements actually make the body more efficient by involving muscles in a slightly different way and reducing the strain on fatiguing muscles?

Injury: The likelihood of injury is increased when running fatigued. Muscles often act to lessen the stress on other lower extremity tissues, and when they get fatigued and movement patterns change, tissues which usually do not sustain high loads must take on some of the burden. Thus a tissue which may be sufficiently strong under normal conditions may become the weak link when fatigue alters the distribution of stresses.

This may be more of an issue for training than for racing. In racing, fatigue cannot be avoided since performance is the overriding consideration. However, during training it might be more rational to balance the physiological benefits of extreme levels of fatigue with the potential musculoskeletal risks. A cleverly devised training regimen might be able to achieve the same physiological benefits without causing intense localized muscle fatigue that puts the runner at greater risk for musculoskeletal injuries.