RUNNING INJURIES: FOREFOOT VERSUS REARFOOT AND BAREFOOT VERSUS SHOD: A BIOMECHANIST'S PERSPECTIVE

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In recent years, there has been a debate regarding the use of different footfall patterns to reduce injury risk and enhance performance. Humans have three footfall patterns available to them when running: rearfoot, midfoot and forefoot. These different patterns are distinguished by the portion of the foot that's makes initial contact with the ground. Interestingly, until very recently, there has been little research to show the pros or cons of the various footfall patterns. Here we will discuss several studies that have been carried out to distinguish footfall patterns in terms of kinematics and kinetics, running economy, the effect of surface and coordination on the risk of running injury.

KEY WORDS: running, footfall patterns, forefoot, rearfoot, barefoot, shod.

INTRODUCTION: Human runners, unlike their closest animal relatives, use multiple footfall patterns that are distinguish from one another by the portion of the foot that initially contacts the ground. These patterns are referred to as: 1) rearfoot (RF) in which the foot initially contacts the gound on the lateral aspect of the heel followed by a forward movement of the center of pressure leading to a toe-off; 2) midfoot (MF) in which the foot initially contacts the ground on the lateral side of the metatarsal heads followed by a heel contact and then a forward progression to toe-off; and 3) forefoot (FF) in which the foot contacts the ground on the metatarsal heads with no subsequent heel contact. In a study of elite Japanese runners participating in a half-marathon race, Hasegawa et al (2007) reported that 75% of all runners used an RF pattern, 23% used an MF pattern and 2% used a FF pattern. Additional studies have also suggested that the fastest runners in short, middle, and long distance events are FF or MF runners (e.g. Kerr et al., 1983). However, there is increasing interest in altering footfall patterns from an RF to a FF pattern in an effort to reduce running injuries even though there is very little evidence to support this hypothesis. Along with the controversy of altering footfall patterns is the barefoot running phenomena. In barefoot running, RF runners often alter their footfall pattern to a MF or FF pattern. Therefore, the simple question of the benefits/lack of benefits of altering one's footfall pattern is also clouded by the advantages or disadvantages of barefoot versus shod running. These questions often become one in the same question.

Kinematics/Kinetics of Different Footfall Patterns: The major difference in the kinematics of RF versus FF running is the position of the ankle at initial foot contact (Figure 1). In RF running, the ankle is dorsiflexed initially with a subsequent plantar flexion for the foot to reach the foot flat position. In FF (or MF) running, the ankle is in a plantar flexed position. This initial position places the Achilles muscle-tendon complex in an eccentrically loaded position during FF/MF running while in RF running, the Achilles complex is loaded minimally during the impact attenuation portion of the support phase.

Using a force platform analysis, it has been reported that loading rates and peak vertical impact forces are reduced in FF compared to RF running and barefoot compared to shod running (e.g. Komi et al., 1987). It has also been suggested that the increased force values are a risk factor for a running injury (e.g. Zifchock et al., 2006). A FF pattern has been suggested to reduce the rate of running related overuse injuries due to the absence of the initial vertical ground reaction force peak (e.g. Lieberman et al., 2010) (Figure 2). However, while the impact peak does occur in the time domain, in the frequency domain, there are components of the signal in the same region of the frequency spectrum as the impact peak from RF running (Gruber et al., 2011). Therefore, impacts are present in both RF and FF patterns during running.

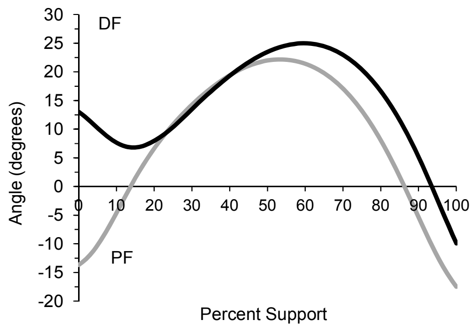

Figure 1. Examplar sagittal ankle angles for RF (black) and FF (gray) footfall patterns.

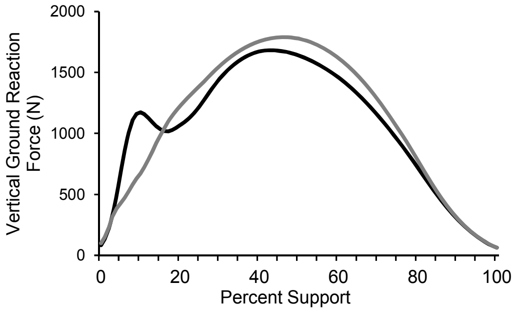

Figure 2. Exemplar vertical ground reaction force component for RF (black) and FF (gray) footfall pattern runners.

Loading rate has also been suggested as a major difference in RF and FF footfall patterns during running (Milner et al., 2006). The suggestion is that by transitioning from an RF to a FF pattern, loading rate and thus injury risk would decrease. However, recent studies have shown that this may not be true. Unpublished data from Iowa State University showed that natural FF pattern runners have a lower loading rate than natural RF runners when running with an RF pattern. However, when running with a FF pattern, the natural FF runners had a higher loading rate than natural RF runners. These authors also reported higher stresses in the tibia during FF running for both groups. In general, there does not seem to be a relationship between kinetic variables and running injury regardless of footfall pattern (Bredeweg, 2011).

Running Economy: Running performance is generally measured by evaluating running economy; that is, lower sub-maximal metabolic energy consumption indicates good running economy. In addition to physiological and anthropometric factors (e.g. Morgan et al., 1994), improved running economy is also affected by biomechanical variables including longer ground contact time, lower vertical GRF peaks, decreased vertical oscillation, greater trunk angle, greater maximum knee flexion in the stance phase and a more extended leg at touchdown (e.g. Williams and Cavanagh, 1987). At present, conflicting results comparing running economy between footfall patterns have been found. Although some studies have not found a difference in running economy between footfall patterns (e.g. Gruber et al., 2009), others have found RF running to be more economical (e.g. Slavin, 1992). The limitation in many of these previous studies is that they did not compare economy between natural RF and natural FF runners. In a recent study, after controlling for stride frequency and shoe mass, runners were 2.41% more economical in a minimal shoe condition when forefoot striking and 3.32% more economical in the minimal shoe condition when rearfoot striking when compared to running in a standard show with each footfall pattern. However, FF and RF footfall patterns did not differ significantly in cost for either minimal or standard shoe running (Perl et al., 2012).
In a forward dynamics modeling study, Miller and Hamill (in press) suggested that the choice of footfall pattern was task specific. With their model, given different cost functions, the model “chose” to run most economically with an RF pattern and to run the fastest with an FF

pattern. However, by using an MF pattern over an RF pattern, the energetic cost of transport increased from 15.0 to 19.9 W/kg or an increase of 1.2 kcal/min.

The major problem with all of these studies is that economy is determined over at most a seven minute running interval. While this time course is fine for the shorter distances, a question arises as to the preferred footfall pattern for longer distances. This is currently unknown although a recent paper reported that most runners who began the race as FF runners changed their pattern to RF midway through the race (e.g. Larson et al., 2012).

The Effect of Surface: Many of the FF and barefoot enthusiasts have suggested that the elevated heels in modern footwear have caused many runners to change to an RF pattern from the more natural FF pattern. There is no evidence for this reasoning. Hamill et al. (2011a) had natural RF runners run in identical shoes with various thicknesses from what is seen in regular footwear to a condition in which there was no midsole (i.e. only an outsole). They also included a barefoot running condition. The results indicated that the runners did not alter their footfall pattern in the shod conditions but did change to a FF pattern in the barefoot condition. In another study, Hamill et al. (2011b) reported that a significant majority of runners changed from their natural RF to a FF pattern when running barefoot on a firm surface. However, when running on a softer surface, the runners maintained their natural RF pattern.

Coordination: Coordination between the rotations of the rearfoot and forefoot segments have been studied using a dynamical systems perspective. Gruber et al. (2011) investigated rearfoot/forefoot coordination in natural RF and natural FF runners who ran using both a RF and FF footfall pattern. Their results indicated that, regardless of habitual footfall pattern, both footfall patterns resulted in an in-phase relationship between rearfoot and forefoot pronation. However, forefoot pronation was delayed in the RF pattern whereas pronation of the rearfoot and forefoot was simultaneous in FF running. That is, the rearfoot/forefoot complex in FF running acted as a rigid segment placing the plantar fascia under continuous strain.

Joint Stiffness: One aspect of running that has not been investigated in the change from shod to barefoot running is joint stiffness. Increasing joint stiffness at the lower extremity joints during running has been implicated in running injuries (e.g. Butler et al., 2003). Hamill et al. (in review) showed that running with an RF pattern required a stiffer ankle joint and a more compliant knee joint. However, in running with an FF pattern, a compliant ankle and a stiffer knee was necessary. Thus, a re-organization of the joint stiffness of the ankle and knee joints is required for runners to change from a RF to a FF pattern.

Conclusion: While there is a great deal of controversy regarding the efficacy of changing footfall patterns from RF to FF and from shod to barefoot, there is still minimal data to show that this change will reduce injuries or alter performance.

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