Running modifications and reducing injury risk

Elizabeth Boyer
Gillette Children's Specialty Healthcare

Timothy R. Derrick
Iowa State University, tderrick@iastate.edu

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Abstract
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By Elizabeth Boyer, PhD, and Tim Derrick, PhD

Runners struggling with injuries may be curious about barefoot running or running on their toes if they’ve seen other runners doing it, or if they’ve heard it will decrease their risk of injury because it’s “more natural.” Although there is evidence in the medical literature that such changes may reduce the risk of some types of injuries in some runners, evidence also suggests injury risk can be reduced using an alternative running modification that might be easier to implement.

Large-scale epidemiological studies objectively quantifying how runners run (ie, footwear or foot strike pattern) and how those variables relate to injury risk are nonexistent. A few studies with either small sample sizes or self-reported information about footwear or foot strike style provide conflicting evidence of injury prevalence in rearfoot, midfoot, and forefoot strikers, and shod versus barefoot runners, though shod rearfoot strikers might sustain more injuries than others.

Beyond foot strike

We need to be wary of studies using self-reported foot strike, though, because
approximately one third of runners misclassify their foot strike style. Additionally, since stride length may slightly shorten when switching from a rearfoot strike (RFS) pattern to a midfoot or forefoot strike (FFS) pattern or when switching from shod to barefoot running, the independent effects of stride length, footwear, and foot strike style appear to be equivocal. For instance, the decreased loading associated with running barefoot versus shod running may be primarily attributed to a shorter stride length, and multiple studies have shown that a shortened stride beneficially decreases loading. So, in addition to, or in place of, running barefoot or using a FFS modification, we might be able to decrease injury risk by retraining runners to use shorter strides.

In our model, we consider the effects of shorter stride length and increased stride frequency to be synonymous. Although these variables aren’t perfectly interchangeable, if running velocity is held constant, stride length and stride frequency vary inversely with each other. In other words, running velocity is equal to the product of stride length and stride frequency. For example, 3 m/s running velocity can be obtained by a stride length of 2.25 m and a stride frequency of 1.33 strides/s (or 160 steps/minute). If the same runner shortened his or her stride by 10% (to 2.03 m) but maintained that 3 m/s velocity, he or she would have to use a stride frequency of 1.48 strides/s (or 178 steps/minute).

**Forces**

Many studies investigating biomechanical differences between foot strike styles and footwear have focused on the vertical ground reaction force (GRF) and how quickly it changes, or GRF loading rate. Several studies have found that runners with high
vertical loading rates are more likely than those with lower loading rates to sustain a future injury or to report a history of injury, particularly of stress fracture. Zadpoor and Nikooyan summarized 13 studies and found that higher vertical loading rate (not peak vertical GRF) was associated with the risk of stress fractures of the tibia and metatarsals. Typically, loading rate is higher with a RFS pattern than a FFS pattern, which is one reason why FFS running is purported to help reduce injuries.

However, focusing only on vertical forces neglects the smaller shear forces. Considering that the leg is relatively perpendicular to the ground during stance and that muscles can apply force only through shortening, the femur and tibia/fibula are primarily loaded in compression. Bones are most resistant to these compressive forces and stresses, and less resistant to tensile forces and shearing forces, such as those caused by shear GRFs. We found that, while habitual rearfoot strikers decreased their peak vertical GRF and loading rate when using a FFS, the shear (posterior and medial) GRFs and loading rates were higher during forefoot striking

Figure 1. The resultant ground reaction force vector (red arrow) is larger and oriented more posteriorly for forefoot strike running (left) vs rearfoot strike running (right) in the early part of stance (~8% of stance). Adapted from reference 38.
than rearfoot striking during impact. These higher shear forces orient the resultant GRF vector more perpendicular to the tibia (Figure 1). We may also want to shift our focus to the resultant GRF and loading rate (ie, summation of all three orthogonal directions), as that force is what the body experiences, and it is always equal to or greater than the vertical force.

Moments

Taking it a step further, we can look at joint moments (or torques), which are surrogates for the net muscle activity at a joint. Joint moments during running have been fairly well documented for the sagittal plane, which is the plane associated with the largest moments during running. Generally, plantar flexion moment and power are greater for FFS than RFS patterns\(^8,11,39-41\) knee extension moment and power are greater for RFS than FFS patterns\(^8,11,39,41,42\) and studies of sagittal plane hip moments have been inconclusive with regard to foot strike.\(^11,41,43\) Similar trends have been reported for barefoot versus shod running.\(^12,15,39,44,45\)

However, the other planes have been largely neglected. Of the few variables that have been investigated, knee abduction moment was higher and ankle external rotation moment was lower for RFS than FFS.\(^11,43\) Compared with habitual midfoot and forefoot strikers, when habitual rearfoot strikers ran with a FFS, they had larger hip abductor and ankle external rotation moments.\(^43\) Additionally, ankle internal rotation moment increased when habitual rearfoot strikers ran with a FFS compared with a RFS.\(^43\) We have supplemented these findings and found similar results with a few contradictions.\(^46\)
Many studies have shown habitual rearfoot strikers can decrease loading by shortening their stride length, but can they decrease it to the same extent as when switching to a FFS pattern? Our preliminary data comparing stride shortening and switching from a RFS to FFS pattern suggest they can for several variables, including peak knee extensor moment, hip internal rotation moment, lateral knee contact force, and posterior hip contact force. Therefore, a shorter stride seems to decrease certain loading variables as much as switching to a FFS pattern. Plus, shortening one’s stride does not increase ankle loads the way a FFS pattern does.

Net joint moments are limited in that they cannot tell us the extent to which all muscles are firing. Instead, they just tell us which muscle group is firing the most. For example, the quadriceps could be producing a +100-Nm moment while the hamstrings produce a -80-Nm moment, resulting in a net joint moment of +20 Nm. However, both of these moments contribute to gross loading at the joint.

Joint contact forces include both joint reaction forces (forces accounted for in net joint moment calculations) and muscle forces, which we can estimate using optimization procedures. It is important to consider these muscle forces, as they account for more of the total joint loading than reaction forces. For instance, peak ankle joint reaction force might be two times body weight, whereas muscle forces might be six to eight times body weight. Only a few studies have reported contact forces for different foot strike styles, focusing on the axial or patellofemoral contact forces. Again, we supplemented their findings with data for all three planes. Interestingly, because co-contraction is ignored in net joint moment calculations, it is possible that moments may be larger for one foot strike style, but contact forces could actually be equal or larger for the other foot strike style, which we observed. The take-home message is that we need to consider muscle forces to get a better understanding of the actual joint loading during running.

**Offsetting effects**
Taken together, the literature suggests that ankle loads are higher for FFS than RFS patterns, while some knee and hip loads are higher for RFS than FFS. Some researchers have observed that habitual rearfoot strikers tend to have higher knee and hip loads than habitual midfoot and forefoot strikers for both RFS and FFS.43,46,49 This continuation of more reliance on the knee extensors may be a lingering effect of the neuromotor programming associated with a RFS pattern. So, even though knee loads tend to decrease when habitual rearfoot strikers switch to a FFS pattern, if they do not decrease to the levels seen in habitual midfoot or forefoot strikers, this could potentially mute the effect on injury risk. Shortening stride length, however, decreases loading to a similar extent. If tolerated by the runner, this alternative to foot strike modification may be a better approach to decreasing injury risk. Additionally, studies have shown that, despite taking more steps per distance with a shorter stride length, cumulative loading (ie, the summation of loading from all steps per distance) remains lower for the shortened stride length condition versus normal stride length.20,25

Although loads may be higher at different joints for certain foot strike styles, bones may adapt so that the actual bone stresses and strains are unchanged. Our preliminary data and those of others have shown that tibial stresses, strains, or strain rates are highest during shod FFS running, moderate for barefoot FFS running, and lowest for shod RFS running.46,50,51 Only shear stress decreased slightly with a shorter stride length.46 As such, if runners’ bones do not have time to adapt to the greater stresses and strains of FFS and barefoot running, running in these strike patterns may load the tibia excessively. Alternatively, if runners transition slowly to FFS or barefoot running, these higher loads may make their bones stronger.

In addition to peak joint loads, certain frontal and transverse plane variables have been linked to running-related injuries, such as patellofemoral pain, iliotibial band syndrome, and tibial stress fractures.32,52-58 We previously investigated how these variables changed with foot strike style and step length in 42 runners.16 Regarding beneficial changes, during FFS, contralateral pelvic drop (which has been associated with patellofemoral pain52,58 and iliotibial band syndrome54) was reduced. During RFS, step width was increased, which is beneficial since a wider step width decreases frontal joint moments,59 iliotibial band strain,60 and peak free moment.61 During RFS, peak negative free moment was also reduced, which is beneficial as research has
linked larger peak free moments with risk of tibial stress fractures.\textsuperscript{30,32} However, variables such as peak iliotibial band strain and strain rate, hip adduction, rearfoot eversion, and positive free moment were not different between RFS and FFS. Therefore, the risk of injuries related to these variables—such as patellofemoral pain, iliotibial band syndrome, and tibial stress fractures—is largely unaffected by foot strike style.

Most variables did, however, slightly decrease as runners used shorter strides, which may have been associated with their concomitant wider steps. Adding to the plethora of data supporting the benefits of shortened stride length, we found shortening one’s stride length may decrease—or at least not increase—the propensity for running injuries based on the variables we measured.\textsuperscript{16}

**Clinical implications**
Collectively, study findings suggest that a single foot strike style does not appear to explicitly decrease injury risk; rather, different foot strike styles may predispose runners to different types of injuries. A shorter stride length, however, may be beneficial.

So, should runners modify their running style to prevent persistent injuries by running barefoot, on their toes, or taking shorter steps? The evidence suggests none of these
modifications universally reduce loading on all structures.

If a runner is experiencing ankle or foot pain (particularly in the metatarsals or plantar fascia), rest is probably indicated, as running barefoot or using a midfoot or forefoot strike or both may make the problem worse. If resting isn’t an option, shortening strides by 10% may reduce loading.

If a runner is experiencing knee or patellofemoral pain caused by excessive loading, either switching to a midfoot or forefoot strike (shod or barefoot) or shortening the stride by about 10% may help. The benefit of only shortening the stride is that the runner won’t be increasing loading on different joints or tissues.

If a tibial stress fracture is the concern, neither switching foot strike nor running barefoot will likely decrease tibial stresses, and the runner may have to use at least a 10% shorter stride length to significantly decrease stresses.

If the runner is experiencing hip pain caused by excessive loading, he or she may decrease loading more by switching to a midfoot or forefoot strike (shod or barefoot) rather than by shortening the stride, though both modifications are options for decreasing load.

It would be logical to consider both running modifications (foot strike and stride length) simultaneously, which researchers have found to beneficially decrease GRF loading rate. Indeed, most habitual rearfoot strike runners instinctively shorten their stride length when running at the same speed with a midfoot or forefoot strike.

What if runners are not injured and just want to switch foot strike style? They can try it, but should transition very slowly (at least 10 weeks or more). Because there is no evidence that a shorter stride length leads to injuries, runners wanting to adopt this modification do not need to transition slowly. As with making any running regimen change, it is important for runners to listen to their bodies to help avoid injury.

Elizabeth Boyer, PhD, is a postdoctoral fellow at Gillette Children’s Specialty Healthcare in St. Paul, MN, studying movement disorders in children and adults. Tim Derrick, PhD, is a professor in the Department of Kinesiology at Iowa State University in Ames studying musculoskeletal loading during activities of daily living.
REFERENCES
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