Running serves a myriad of purposes in our lives. Whether we are catching the bus at the last second or competing in an international athletic competition, running is so common and familiar a movement that we rarely turn our attention to this surprisingly complex action. An understanding of the physics and biology of running encompasses an extensive range of dynamic factors that influence the strides we make, from the motion of our joints to the material of our sneakers. Here, through the lens of biomechanics, we take a closer look at how we run.

What’s in a stride?

One of the most basic classifications of our gait is speed. Running involves a very different pattern of movement of the feet and legs compared to walking. Walking is defined as having two moments where both feet touch the ground in a single gait cycle, which refers to a single cycle of stride motion where a person finally returns to the initial limb arrangement at the beginning of the stride (1). In contrast, running involves two moments in the gait cycle where both feet are in the air (1, 2).

A review published by Tom Novacheck in 1998 titled “The biomechanics of running” summarizes much of the biomechanics research on running and provides a comprehensive glimpse into the fundamentals of the running, walking, and sprinting gait (1). Scientists have recorded the vertical and angular movement of joints and bones, revealing the contribution of certain parts of the leg to the motion of walking, running, and sprinting. This has been done through the use of center of pressure measurements, force plate experiments, electromyographic activity, and kinematics analysis of specific joints (1). The full analysis is quite complicated and involves substantial familiarity with anatomical structures. Nevertheless, there are several fascinating highlights among the findings regarding the kinematics of running.

At the most fundamental and physical basis, we move because we apply a force...
to the ground by our feet—and the ground, by Newton’s Third Law of Motion, applies an equal but opposite force on us. This ground reaction force is what propels us forward. However, Novacheck notes that our center of mass doesn’t always move forward when we move. Upon reaching maximum speed after starting from rest, the sprinter’s center of mass begins to move backwards as the sprinter starts assuming a different posture. In order to counteract this backward center of mass motion—which would otherwise make the sprinter fall over backwards as well—the sprinter must continually lean forward (1). From an intuitive perspective, this seems quite natural. Much of the findings reviewed by Novacheck, despite their more complicated technical basis, do in fact corroborate well with experience. For example, from watching Olympic sprinters it certainly appears that world-class track athletes bring their knees much closer to their chest as they move compared to typical runners. This is indeed what is shown by a kinematical analysis: the knee flexes (or bends) more if we move faster (1). Interestingly, the general pattern of motion for our thighs is the same for when walking or breaking world running records – with the only main difference being how high our thighs move (1).

Finally, Novacheck highlights a significant difference between running and walking when viewed from an energetic standpoint. During a walking stride, our potential energy increases as we move upward while our kinetic energy decreases. On the other hand, for running, both our potential energy and kinetic energy decrease while we are in the air, but are at their maximum when we are on the ground (1). This has led to a basic model for running - analogous to that of a pogo stick. Like the spring motion of a pogo stick that pushes us upward and forward, our legs store energy which is then released as we run. In contrast, walking is traditionally modeled more like a pendulum and has been dubbed “controlled falling” (1).

The quest for the perfect shoe

With all these studies, it would seem as if we know all there needs to be found about how we move. However, such a conclusion is far from reality. Much of the complexity involved with running involves the precise coordination of many parts of our body, including our arms, trunk, and the ligaments and muscles in our legs. Furthermore, each individual’s gait is unique - further complicating our understanding of running.

The challenge of precisely understanding the mechanics of running is no more apparent than in the quest to design the perfect running shoe. Many sneaker advertisements propose the comfort and effectiveness of their product to consumers of all age groups, whether through targeted motion control, arch support, or flexibility in synthetic material. The difficulty in designing a shoe that reduces the discomfort of long-distance running and prevents running injuries from long-term foot impact stems from the lack of details we have regarding the mechanism of running and how shoes are involved in the movement.

Attention to the development of biomechanically healthy running footwear has increased since the 1970’s, and there has been a great deal of research analyzing the basic anatomical and kinematic mechanism of running. Running footwear recommended between the 1970’s and the 2000’s generally involved rigid, wide heels that were supposed to reduce force to the heel and stabilize the motion of the foot. Such constructions, however, created different problems and potential injuries (3).

For the past decade, the use of newer technologies such as pressure distribution measurement has greatly influenced and improved shoe design. With a greater base of knowledge and

![Figure 1. The sprinter’s knees bend more than the average runner’s because he is moving at a much faster rate. The thighs are lifted higher as well. Also notice how both feet are off the ground for the sprinter at the right.](image-url)
Focus: The Science of Energy

data, past assumptions about running shoe design have been discarded and replaced. For example, the creation of unstable running footwear has shed light on the concept of stability for future shoe designs (3). Moreover, a 2008 scientific review concluded that the general practice of recommending “pronation control, [and] elevated cushioned heel” running shoes to prevent long-term injury for distance runners was not based on systematic evidence and clinical trials and has warranted greater scientific evidence to support such practices (4). (Pronation refers to the amount the foot rolls as it hits the ground while running; over-pronators roll inward towards the big toe and under-pronators roll outward (5).) Biomechanics is a rapidly-developing scientific field, and with better techniques for analysis scientists and footwear companies will be able to better collaborate in designing and evaluating the function of more comfortable and injury-reducing footwear both for the everyday runner and for the competitive athlete.

While the science behind the perfect for women. A recent study conducted in 2009 concluded that the selection of footwear “was a statistically significant, predictive factor of hindfoot pain” in women, while no similar conclusion could be made for men because “less than 2% wore poor shoe types” (9). In this survey, good footwear consisted of athletic footwear and sneakers, whereas poor footwear included heels, slippers, and sandals.

Finally, Dr. Scholl’s pain relief orthotics products are regularly advertised to the consumer market as a solution to make our strides more comfortable. But do they work? Dr. James P. Ioli, chief of podiatry at the Brigham and Women’s Hospital, notes in the Harvard Health Letter that orthotics “are worth a try…the flat, foam, and gel orthotics cushion the foot nicely,” but he also warns that they will likely not reduce back and knee pain significantly (10).

Is barefoot better?

A 2009 study led by Cedric Moreio concluded that footwear heavily influences gait. The group of researchers from France and the UK compared the kinematics of running and walking in sandals to the kinematics of barefoot motion and found that sandals significantly alter the way we land on the ground (11).

Studies similar to this one are being published just as the barefoot movement is starting to gain prominence. Shoes that allow runners to adapt to a natural, barefoot motion such as the Vibram FiveFingers footwear have become increasingly popular, and major footwear companies such as Nike and New Balance have begun to push shoe designs that mimic barefoot-running while maintaining some degree of cushioning (12).

Daniel Lieberman of the Department of Human Evolutionary Biology at Harvard and his colleagues recently took a more detailed, scientific look at the differences between habitually running with shoes versus habitually running barefoot. In a study reported in Nature in January 2010, Lieberman’s group statistically analyzed the kinematics between American athletes

![Figure 2. Typical athletic footwear, with a relatively thick heel and cushioning.](image)
who typically ran with running shoes and those who had switched to minimal footwear or barefoot running. The researchers also examined the motion patterns for runners from Kenya who were either raised with shoes and ran with shoes, raised barefoot but now ran with shoes, or raised barefoot and still did not wear shoes (13).

There was a remarkable difference between runners with shoes and runners without shoes. Although typical runners with shoes strike the ground first with the rear part of the foot (heel), barefoot runners naturally strike the ground first with the front or middle of their feet. Landing on the front or middle part of the foot reduces the impact with the ground, which likewise can reduce injury to long-distance and habitual runners (13). William Jungers of Stony Brook University Medical Center noted in a Nature news briefing that these results offer some compelling evidence in support of minimalist shoe constructions, and that future similar studies would contribute further to our understanding of both shoe and running practices (14).

**Outlook**

Although a simple and natural action, running is indeed a complex process from the perspective of biomechanics. Scientists are continuing to understand the mechanism of our motion, ultimately in an effort to make our strides more comfortable and injury-proof. While much remains to be understood, whether barefoot or with a pair of running shoes, we should continue to enjoy this healthy activity that our bodies have been so naturally designed to do. 

—Jennifer Lu ’14 is a prospective Chemical and Physical Biology concentrator in Greenough Hall.

**References**

5. Runner’s World. “Promotion, Explained.” URL: http://www.runnersworld.com/article/0,7120,s6-240-319-327-7727-0,00.html
12. Parks, Bob, “Is Less More: Minimalist Running Shoes.” Runner’s World. URL: http://www.runnersworld.com/article/0,7120,s6-240-400--13691-1-1x2/3x4s5x67x8-9,00.html
ADVERTISE WITH THE

HARVARD SCIENCE REVIEW.

harvard.sci.review@gmail.com
Look forward to “A Decade in Review” in Spring 2011!

in the
HARVARD SCIENCE REVIEW