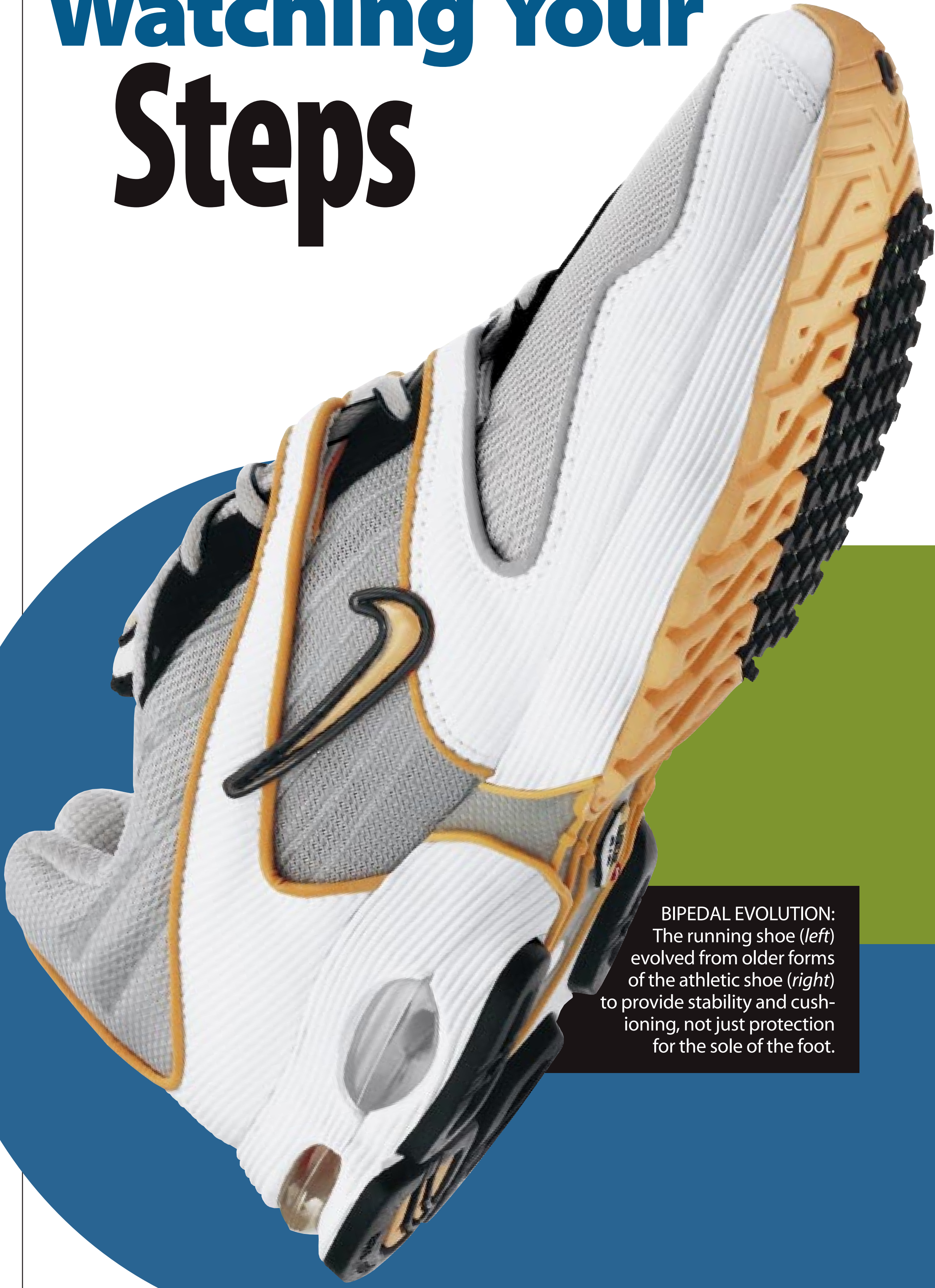
Watching Your Steps



BIPEDAL EVOLUTION: The running shoe (*left*) evolved from older forms of the athletic shoe (*right*) to provide stability and cushioning, not just protection for the sole of the foot.

A new appreciation of the diversity of running styles may eventually yield shoes custom-fit to their wearers

by Karen Wright

Running is often called a "pure" or "simple" sport. It doesn't have many rules, it doesn't take much teamwork, and it requires little in the way of equipment, training and talent. Almost anybody with two legs and a healthy heart can run, almost anytime and almost anywhere. There is, of course, a yawning chasm between recreational joggers who log a few miles after work and the cabal of athletes who win marathons and Olympic medals. But just about everybody who runs farther than to the bus stop uses the one and only piece of specialty gear the sport demands: running shoes.

COURTESY OF NIKE INC. *(left)* AND CONVERSE INC. *(right)*

Most people can't imagine running without them. Casual athletes wear running shoes to protect against injury by cushioning impact and aiding joint alignment. Serious runners count on their shoes to improve their performance as well. How and whether running shoes deliver on these expectations are questions science has been trying to answer since the word "sneaker" went the way of the hula hoop sometime in the 1970s. After decades of investigation and millions of dollars of investment, the running shoe is still very much a work in progress. In fact, its brief history can be seen as an ongoing experiment in biomechanics, materials and design.

Elite runners' quest for better fit, better protection and better times has driven a technological renaissance that has reached far beyond the track. Its repercussions can be felt today in most specialized sports footwear and even the humblest walking shoe—not to mention the wallet. Meanwhile all the brainpower and high-tech analysis brought to bear on the running shoe in recent years have been toppling some cherished assumptions. The roles of impact and alignment in running injuries and athletic performance turn out to be more subtle and complex than anyone expected. But some of the latest lessons to come off the treadmill are surprisingly simple: Bare feet know best. Go with what feels right. And when it comes to running shoes, one size—or style or shape or sole—will never fit all.

"Shoe companies wage a constant battle to get a shoe with an adequate amount of both shock absorption and stability," says Jack Taunton, co-director of the University of British Columbia's Allan McGavin Sports Medicine Center. As the leader of major studies tracking thousands of runners' injuries over the past three decades, Taunton is well acquainted with the classic trade-off between the two aims. Shock-absorbing materials such as trapped gas, silicone gel and foam polymers cushion the impact of pounding feet, long blamed for the most insidious running injuries. But too much cushioning compromises a shoe's ability to stabilize the alignment and movement of the joints in the legs and feet. Taunton attributes a rise in Achilles tendinitis in the late 1980s to a concomitant increase in the popularity of soft heels in running shoes. "When the heel gets too soft, the foot sinks into it and torques, and then you get more Achilles problems," he explains.

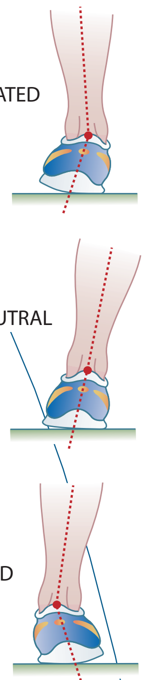
CONTROLLING ROLL

Stability features such as stiffer soles, racing stripes and arch supports are meant to steady the foot within the shoe and guide its contact with the ground. But a shoe that's too rigid won't protect against impact and can restrict the complex series of motions that make up a normal gait cycle. These days, for ex-

Stylistic Differences

[redacted]

The right foot of three different runners during the middle of a step makes contact with either the outside of the foot (supinated), the entire surface (neutral) or the inside of the shoe (pronated).



Summing the Parts

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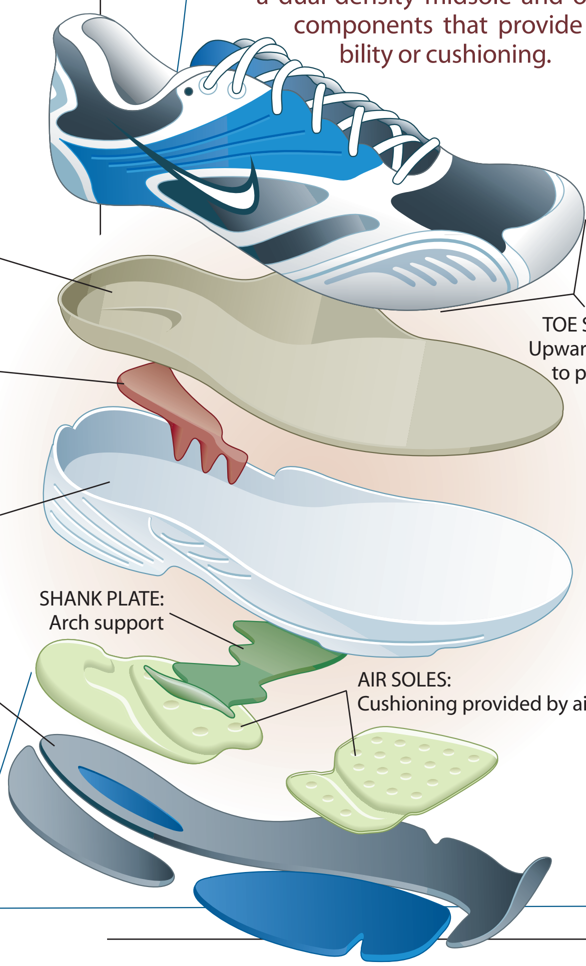
The Nike Air Structure Triax 5, a recent typical running shoe, contains a dual-density midsole and other components that provide stability or cushioning.



SAMUEL VELASCO

ample, many running shoes have a built-in support called the dual-density midsole, a polymer layer between the outsole and insole that is firmer under the arch than along the outer side of the shoe. The firm arch was designed to prevent excessive pronation, or inward rolling of the foot, as the runner's weight shifts from heel to toe.

But some amount of pronation is natural and even necessary in normal walking and running. After the dual-density midsole was introduced in the early 1980s, Taunton says, he saw a sizable increase in the frequency of iliotibial-band friction syndrome, a condition in which a band of connective tissue running down the outside of the thigh rubs painfully against a bony protrusion near the knee. Taunton thinks that the early dual-density technology may have caused normal pronators to roll too far onto the outer edges of their feet—a motion called supination that is also part of normal running but that can be harmful in excess. Oversupination stretches the iliotibial band and causes the long bone of the thigh to twist inward, increasing the friction between the band and the bony knob.

Manufacturers also wage the battle between cushioning and stability in their efforts to reduce the weight of their shoes, because stability components tend to be heavy. "We're constantly trying to get the shoes lighter-weight without making them too flexible," says Martha Sutyak, design manager of New Balance Athletic Shoe in Boston. The biggest breakthroughs in strong, lightweight materials happened decades ago, during the chemical revolution, when nylon replaced leather and canvas uppers and the now ubiquitous foam polymer called ethylene vinyl acetate (EVA) supplanted rubber in the midsole and heel. Since those innovations, most progress in weight reduction has consisted of removing unnecessary material—strategically carving out the surplus EVA in perforated midsole designs such as New Balance's "stability web" or Saucony's "grid" technology.

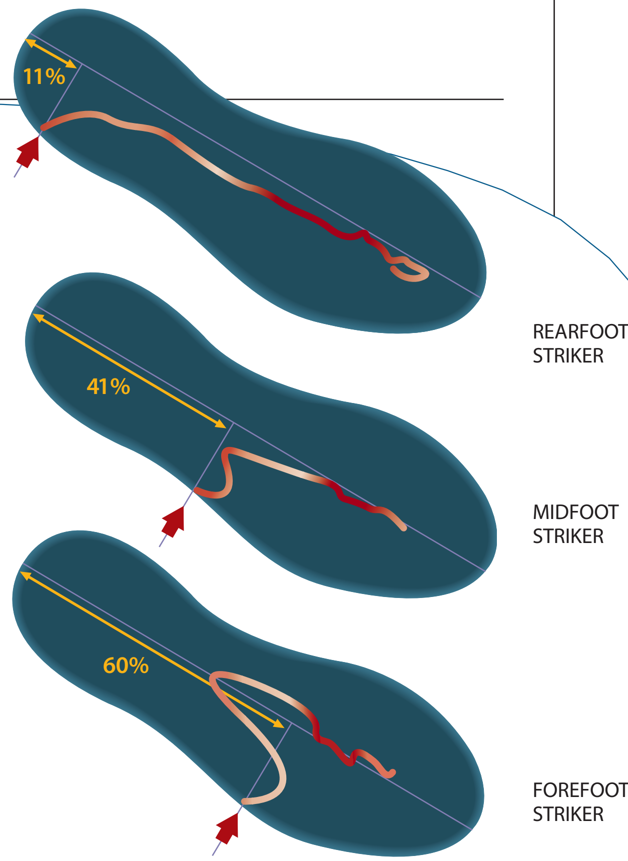
BAD VIBRATIONS

While shoe manufacturers struggle to strike the right balance between cushioning and stability, biomechanics research is challenging fundamental assumptions about the roles of both. At the University of Calgary's Human Performance Laboratory, director Benno M. Nigg has marshaled evidence that the jarring effects of road running may not be nearly as pernicious as once thought. Nigg says he himself needed to be convinced: it's clearly more comfortable to run in track shoes than in brogans. But when he set out to quantify the relation between impact forces and running injuries, Nigg found that there wasn't one. His tests showed, for example, that fast runners land with two or three times the force of slower runners and yet are injured no more frequently. In fact, the runners who experienced the highest-impact forces had fewer injuries than the lowest-impact runners did.

Nigg cites similar results from other labs. It turns out that running on hard surfaces produces no more

Pressure Points

Rearfoot, midfoot and forefoot strikers land on different places on the outside of the right foot (*arrows*). The red band traces how the center of pressure tracks along the foot. The percentages show how far from the heel contact is first made.



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injuries than running on soft surfaces. Impact exercises such as basketball, gymnastics and running have been found to increase bone mass and integrity more than swimming and other low-impact activities do. And although it's reasonable to suppose that degenerative joint diseases such as osteoarthritis would afflict runners more often than nonrunners, they don't. "The concept of impact forces as a major source for running injuries is not well understood," Nigg concludes in a paper scheduled to appear in the *Clinical Journal of Sports Medicine*. "The paradigm of 'cushioning' to reduce the frequency or type of running injuries should be reconsidered." Contrary to prevailing assumptions, high-impact running has not produced an epidemic of injuries, Nigg says.

What, then, can account for the injuries that sideline up to two thirds of serious runners in any year? And why are cushioned shoes more comfortable than stiff ones? Nigg has proposed a novel explanation based on the vibrations in soft tissue that are generated when a runner's heel strikes the ground. His studies demonstrate that just before ground contact, muscles throughout the body tense up in order to counter soft-tissue vibrations. Thus, runners' flabby parts jiggle far less than predicted from impact forces: "The only part that jiggles are women's breasts, where you don't have any muscle," he says.

Furthermore, there's a so-called natural frequency at which each individual's soft tissue "wants" to vibrate, Nigg remarks. Just as guitar strings of different lengths and diameters resonate at different frequencies when plucked, so resonance occurs at different frequencies in different people. The natural frequency of a runner's body depends mostly on weight and muscle tone. And the cushioning in running shoes can amplify or damp soft-tissue resonance by shifting impact frequencies toward or away from a runner's natural frequency.

These variations help explain why individual runners have preferences for a particular shoe style. For each person, some shoes will increase soft-tissue vibrations, and others will decrease them. Nigg believes that fatigue and injury result when the muscles expend too much energy countering soft-tissue resonance. With the right shoe, that energy is freed up, and a runner can expect gains in performance of as much as 5 percent—the equivalent of eight minutes in a marathon.

Nigg's ideas still need to be backed up in the lab. But his theory is part of a growing body of research cataloguing the differences among runners' bodies rather than their common ground. Marathoner and biomechanist Peter Cavanagh first confronted the differences in running styles decades ago, when he began conducting analyses of ground-contact patterns in his laboratory at Pennsylvania State University. At the time, the prevailing model for ground contact in running was so simple it seemed obvious: a runner lands on his heel, rocks forward through his instep and then presses off from the forepart of the foot. The heel strike, with its associated impact forces, was considered the most treacherous phase of the gait cycle. Midstance, with its threat of overpronation, was also receiving considerable attention in shoe research and design.

Cavanagh used a force-sensitive platform embedded in a test track to quantify the location and magnitude of forces on the sole of the foot from heel strike to toe-off. His results surprised him. Sure enough, most of his runners did land on the back part of the foot. But they planted on the outside edge of the heel rather than the middle. Another group of runners, going the same speed, landed on their insteps, then shoved off from the forefoot. A third group both landed on and took off from about the front third of the foot. These groups would become known as rearfoot, midfoot and forefoot strikers, respectively. And within each group, Cavanagh found an infinite variety of ground-contact pat-

GAIT WATCHING: The University of Calgary's Human Performance Laboratory measures the forces on the sole throughout the different phases of a shoe's contact with a force-sensing platform (*foreground*), an action that is captured by tripod-mounted high-speed cameras.

BILODEAU/PRESTON

terns. "When studied in fine detail," he wrote in his 1980 classic, *The Running Shoe Book,* "the pattern of ground contact can be as individual as the runner's voice, something unique and identifiable."

Cavanagh's studies showed that running biomechanics were more complex and idiosyncratic than anyone had suspected. And he proceeded to question another tenet of track lore: the treachery of the heel strike. His data clearly indicated that the forces applied to the front part of the foot during toe-off could be several times greater than those associated with the impact of touchdown.

"At the time, running shoes were wafer-thin under the metatarsal heads," Cavanagh says, referring to the region where the toes meet the ball of the foot. "Our studies pointed to the fact that that needed to change. And it did change."

Today's running shoes are indeed padded from heel to toe. But the forefoot is still a vast terra incognita for many runners and manufacturers, who may have little interest in or knowledge of the contribution it makes to running. A good example is the toe spring, the slight upward curve of the sole at the front of almost all running shoes. "The thinking is that the running stride will be more efficient since there will be a natural rocking forward onto the forepart of the shoe," Cavanagh explained in 1980, when the toe spring was a new gimmick. "As far as I know, the evidence for this supposedly 'more efficient toe-off' does not exist except in the minds of manufacturers and inventors."

Twenty years later evidence of the toe spring's efficacy is still lacking. Now the philosophy of many manufacturers is shifting to favor a more relaxed, flexible forefoot, made with soft materials and strategically placed grooves on the sole to allow toe-off the way nature intended. Nigg's colleague Darren Stefanyshyn has shown recently that toe springs may actually interfere with propulsion by preventing the toes and the balls of the feet from pushing fully down against the ground. "We just constructed a shoe that doesn't have [the toe spring], and we increased sprinting time in the average runner by two tenths of a second," Nigg claims. Because Nigg works closely with athletic-shoe manufacturer Adidas, his views on the toe spring may soon be reflected on retail shelves.

RUNNING INTO A BRICK WALL

Changing ideas about stability and alignment are also challenging running-shoe features designed to control pronation. At the Nike Sports Research Laboratory in Beaverton, Ore., scientists have come to question the use of rigid devices such as dual-density midsoles and footbridges. Such devices create abrupt barriers to the natural inward rolling of the foot, says lab director Mario Lafortune: "It's like trying to stop pronation with a brick wall." That strategy has become less desirable as research such as Cavanagh's has demonstrated that some pronation is normal and even necessary to transfer weight from the outside edge of the foot, where most people land, toward the foot's midline.

Instead of blocking pronation, Lafortune says, he and his colleagues are trying to slow it down. Sudden pronation is more forceful and potentially harmful than gradual pronation, he explains, and some simple modifications to existing shoes can ease the passage. The "crash pad" on the outside edge of the heel can be softened to compress more easily, so that the foot isn't rushed out of its mildly supinated landing position. Similarly, the midsole in the rear third of the shoe can be thinned and rounded toward the outside edge. Nike has already incorporated these adjustments in several retail models, and last year Asics released its first shoe designed to slow the rate of pronation.

And in addition to using external devices to stabilize alignment, Lafortune's team is looking for ways to enhance the foot's natural rigidity. In barefoot running, that rigidity is supplied by the windlass mechanism, a tightening of the bands of connective tissue that run between the heel and the base of the toes. When the toes bend back during toe-off, the bands become taut, locking the long bones of the foot, deepening the arch and causing a slight resupination that centers the foot for push-off. A foot that is both rigid and resupinated provides the safest and most efficient propulsion, Lafortune maintains. And it's best to let the foot stabilize itself rather than to impose stability through rigid elements in the shoe.

CHAMPIONING BARE FEET

Lafortune is reluctant to share how Nike plans to harness the windlass mechanism in upcoming designs. But, again, a softer and more flexible forepart is probably in the works. And barefoot movement is becoming a byword in biomechanics labs outside Oregon. Based on his studies comparing runners' alignment with and without shoes, Nigg—who pioneered the dual-density midsole—now doubts the wisdom of aggressive measures to correct overpronation. For one thing, no one has determined how much pronation is too much; what counts as excessive seems to vary from person to person. Nigg thinks each body has a preferred pattern of movement, revealed in barefoot running, that it adheres to despite orthotic intervention. If shoes promote that preferred alignment, they'll feel great and improve performance; if they work against it, they'll irritate and exhaust the runner. But there's no single, ideal skeletal alignment for running and no systematic corrective strategy that will work for all runners. "That's why if you go to five podiatrists, show them your feet and tell them what you do, you'll get five different [shoe] inserts," Nigg says.

As the running-shoe paradigm dissolves into relativism, how can the average runner hope to find the right shoe? The time-honored method of trial and error is actually quite effective, explains Nigg: "There's a very high correlation between what people call comfortable and where the muscle work is minimal."

But reinforcements may be on the way. Nigg has already approached manufacturers with a plan to group all shoe models according to parameters such as degree of cushioning, dynamic alignment and shape, so that runners who have found a shoe that works for them can readily identify other models with the same properties. Nike is hoping to persuade running-specialty stores to perform biomechanical analyses that would characterize customers' running styles. Microelectronic sensors in shoes could monitor properties such as pressure and compression, Cavanagh says, and change cushioning and stability features to accommodate different body weights, running surfaces and patterns of ground contact.

Even if shoe producers pass the baton to microchips, the market is likely to continue to offer a bewildering array of choices. It all seemed so much simpler 30 years ago, when the late, legendary University of Oregon track coach and Nike co-founder Bill Bowerman cooked his first rubber sole on a waffle iron. Perhaps the trouble is that the history of running is so much longer than the history of the running shoe.

At some point soon after the demise of knuckle walking, running must have become essential to the survival of the human species, whether it was running after or running from. The idea of recreational running is a newer invention, and the running shoe is younger still. "We're always busy testing advanced concepts and technologies, but those always have to do with the same old problems: cushioning, stability and fit," says New Balance's Sutyak. Like a long-distance runner circling a one-mile track, running shoes will keep coming back to the starting line.

BENNO M. NIGG *University of Calgary*

QUO VADIS? Markers attached to a runner's leg reflect light so that high-speed cameras can determine leg and foot positions.

KAREN WRIGHT is a longtime science writer and a former editor at *Scientific American.*

FURTHER INFORMATION

RUNNER'S WORLD COMPLETE BOOK OF RUNNING: EVERYTHING YOU NEED TO KNOW FOR FUN, FITNESS AND COMPETITION. Amby Burfoot. Rodale Press, 1999.

IMPACT FORCES IN RUNNING. Benno M. Nigg in *Current Opinion in Orthopaedics,* Vol. 8, No. 6, pages 43–47; November/December 1997.