FUNNY FEET

Human feet are far more varied than we thought and – no offence – yours are weird, says **Laura Spinney**

GALLERYSTOCK

MY RUNNING shoes have a thick sole and cushioned heel. I bought them five years ago, before the "barefoot" craze for minimalist shoes that would allow people to better emulate how our ancestors ran. Soon after that, reports began appearing of injuries sustained by runners who had adopted these shoes, and lawsuits were filed against some manufacturers. Now the maximally cushioned or "fat" shoe is back in vogue, and suddenly my old shoes look high-tech again.

Is all this simply a matter of fashion, I wonder, or is it telling us something more profound? Surprisingly, we are only beginning to discover what a normal human foot looks like, how it should move, and the role that shoes play. Recent research, sparked in part by the fallout from barefoot running, reveals enormous diversity in healthy feet. What's more, the average Western foot turns out to be an outlier, deformed with respect to our ancestors' feet and those of our barefoot contemporaries. Much of this is down to shoes, which have taken over some of the work our feet had to do to allow us to become bipedal. "We assume that the people around us are normal, but from an evolutionary perspective, they're not," says evolutionary biologist Daniel Lieberman at Harvard University.

The anatomy of the human foot is no mystery. It is a complex structure, containing 26 bones and over 100 muscles, tendons and ligaments. It is also malleable, as will be obvious to anyone who has seen photos of young women's feet bound according to a gruesome old Chinese custom, ostensibly to make them dainty. Some victims wound up with feet that looked as if they had inbuilt high heels.

Foot shape is the product of gene-environment interactions, but how do they play out? Until recently, the few studies there were had focused almost exclusively on Westerners – which, in practice, meant people who had worn shoes since they could walk. Lieberman and his colleagues were among the first to cast their net more widely. In a study published in 2010, they found that Kenyan endurance runners who had grown up without shoes landed more often on their toes than on their heels as 80 per cent of shoe-wearing distance runners do. The work helped to trigger the barefoot running craze, but Lieberman points out that the sample size was small and that the results didn't support many of the claims later made for barefoot running, such as the idea that it reduces the risk of injury. However, the hint that wearing shoes could have such a big impact on how we use ›

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CINDERELLA'S LEGACY

"Things started to go wrong in the 16th century," says Marquita Volken, a shoe archaeologist who runs the Shoe Museum in Lausanne, Switzerland. It was then that European streets began to be paved and the soles of shoes began to get thicker to cushion urban feet. Influenced by the vagaries of fashion, heels rose and both men and women were soon tottering on platforms up to half a metre high. These were the peacock's tail of footwear, a showy badge of social superiority, says Kristiaan d'Août of the University of Liverpool in the UK – since there was no way the wearer could work in them.

The French Revolution brought everyone back down to earth, and when heels started rising again the trend only affected women's shoes – probably, d'Août suggests, because they exaggerated the female aspects of gait. A recent study hints this could have benefits. It showed that men's (but not women's) helpfulness towards a woman was correlated with the height of her heels (*Archives of Sexual Behavior*, DOI: 10.1007/s10508-014-0422-z).

High heels are not good for feet, however, especially when shoes also constrict the toes. Studies of premodern European skeletons suggest that hallux valgus – the condition commonly known as the bunion – started to become prevalent in the 16th century, and has never been more common in women than it is now. A 1993 survey of American women showed that 88 per cent wore shoes that were too small for them, 80 per cent reported pain, and 76 per cent had some sort of foot deformity, bunions being the most common (*Foot & Ankle*, vol 14, p 78). "Shoe design is cyclical," says Volken, whose new book *Archaeological Footwear* chronicles the development of shoes from prehistory to the 1600s. "We're currently in an unhealthy phase."

"Three-quarters of women reported having some sort of foot deformity"

our feet was intriguing, and Lieberman and others have pursued its implications.

A team led by biological anthropologist Kristiaan d'Août, then at the University of Antwerp, Belgium, also did pioneering work in this area. In 2009, they measured the feet of 70 Indians who didn't wear shoes and compared them with those of 137 Indian and 48 Belgian shoe-wearers. They also asked all three groups to walk on a pressure-sensing treadmill, which generated dynamic pressure maps of the foot as it hit the ground.

The barefoot walkers tended to have relatively wide feet, with pressure fairly evenly distributed over the parts touching the ground when walking. The shoe-using Indians had narrower feet and a less even pressure distribution. But the Belgians, who wore more constricting shoes, more often than the shoe-wearing Indians, had very different feet: relatively short and slender, with pressure hotspots at the heel, big toe and midfoot region of the metatarsals (see diagram, right).

Floppy feet

The researchers concluded that shoe-wearing is one of the most powerful environmental factors influencing the shape of our feet (*Footwear Science*, vol 1, p 81). It can also have a big impact on the way we walk, as anthropologist Jeremy DeSilva and gait expert Simone Gill, both at Boston University, discovered. They persuaded nearly 400 adult visitors to the Boston Museum of Science to walk barefoot over a 6-metre-long "gait carpet", which measured speed and stride length as well as building pressure maps. This revealed something remarkable. Around 1 in 13 people were extraordinarily flat-footed: they had a pressure hotspot resulting from their midfoot moulding to the ground as they walked. "Their feet were as flexible as chimps'," says DeSilva (*American Journal of Physical Anthropology*, vol 151, p 495).

As humans evolved to be bipedal, our feet developed longitudinal and transverse arches. These created rigidity in the central part of the outside of the foot, to help propel us forward when we lift our heel and push down on the ball of the foot. In other words, a rigid midfoot is a signature of bipedality. Chimps lack this rigidity, their feet being floppier in the middle to allow them to grip a branch. In technical terms, they have a "midtarsal break", and it's this that DeSilva and Gill observed in some museum visitors. Since publishing their finding in 2013, they have ruled out the possibility that the midtarsal break runs in families. In other words, it isn't strongly

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heritable, although a predisposition to it could be. Instead, DeSilva suspects that it is mainly a result of wearing shoes. "The shoe provides the rigidity, in a way, so the foot doesn't have to," he says.

Two studies published by Lieberman and colleagues last year seem to back this conclusion. In one, they looked at the feet of Tarahumara Native Americans in Mexico – famed endurance runners whose traditional sandals inspired minimalist running shoes – and found that those who ran in sandals had stiffer arches than those who ran in conventional shoes (*Journal of Sport and Health Science*, vol 3, page 86). The other study showed just how quickly feet can adapt. After 12 weeks of regular running in minimalist shoes, Western runners developed significantly stiffer arches.

What goes on within our feet as we walk is still a bit of a mystery. The pressure map method can only give an indirect measure of the mechanics involved. But a novel technique pioneered by Paul Lundgren at the Karolinska Institute in Stockholm, Sweden, and colleagues, takes things a step further. They surgically implanted metal pins into nine bones in the feet of six volunteers, and capped the protruding ends with reflective markers that could be tracked using motion-capture cameras. The technique revealed that all the joints in the foot and ankle contribute to the way we walk, the movement of each joint being dependent on the others (*Gait & Posture*, vol 28, p 93). It also showed great diversity among individuals in the range of movement of each joint – especially in the midfoot.

A team at the University of Liverpool, UK, led by Karl Bates, has replicated that finding in a group of 45 volunteers, using pressure maps. Their study also included bonobos and orangutans, revealing the pressure of human footfalls to be as diverse as those measured in these most arboreal of apes. "What the bone-pin study showed is that everybody is different," says Bates. "For some people the foot is stiff, but for others there is actually a surprising amount of movement."

This natural variation raises important questions. First, if "normal" covers such a wide range, what is an abnormal foot? In the past, foot disorders have been defined as much by social concerns as by medical ones. For example, flat feet were regarded as a sign of moral flabbiness in the American character, according to medical historian Beth Linker of the University of Pennsylvania, Philadelphia, (*Social History of Medicine*, vol 20, p 91). During the first world war, a soldier could be invalided out of the US army for flat feet – but not for shell shock – and flat-foot camps, designed to rehabilitate the afflicted, spread across the country.

Doctors also have misconceived ideas about feet. "The human foot is supposed to be very stiff, and if it's not then often a clinical problem is diagnosed," says Bates. But he and others have shown that flat-footedness isn't necessarily associated with pain or any radical restriction of function. None of the flexi-footed visitors to the Boston Museum of Science complained of pain. And although DeSilva suspects that people with mobile midfeet may not figure among the fastest runners, because they have less elastic recoil when they push off the ground, they pay no obvious price in terms of health.

Bates believes the new findings should also change the way we interpret hominin fossils, because the bones of one individual may tell us little about how its foot worked, let alone how other members of the species walked. Take Lucy, the famous 3.2 million-year-old australopithecine unearthed in Ethiopia, who carries all the hallmarks of bipedalism. When DeSilva compared her ankle bones with X-rays of modern human feet, he concluded that she was probably flat-footed in a non-pathological way. It's hard to say how typical of her kind she was, though. "There would have been variation in her species as in ours, but perhaps around a different norm," he says.

We still have much to discover about what normal means when it comes to feet but one thing is clear. Although going barefoot was normal for most of human evolution, our relatively short period of footwear use – about 40,000 years, according to the archaeological record – has left its mark. That's largely because the human foot turns out to be so plastic. This finding, in turn, holds hope for anyone wanting to turn back the clock. We may be able to run more like our ancestors if we take it gradually, realising that in donning minimalist shoes we load our bodies differently, and that the surfaces we run on are quite different to what they coped with. Nevertheless, the jury is still out as to whether barefoot shoes bring better performance or fewer injuries. Until it delivers its verdict, I'll be hanging on to my old running shoes. ■

Born to run: do stiffer arches give Tarahumara runners the edge in ultramarathons?

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