

BIOMECHANICS

Your sensitive sole

Thick foot calluses develop naturally when walking barefoot. It emerges that they preserve foot sensitivity while offering protection, thus avoiding the trade-off between the two that occurs with cushioned shoes. SEE LETTER P.261

KRISTIAAN D'AOÛT

By approximately 6 million years ago^{1,2}, our hominin ancestors walked upright. Since then, ancient hominins, and eventually humans, have used their feet as their only point of contact with the ground. Evidence suggests that, long after our species evolved about 200,000 years ago to become anatomically modern humans (our current form)³, some people began to wear shoes for protection and for many other reasons — beginning about 40,000 years ago⁴. But wouldn't it be great if foot protection existed that could preserve our sensation (termed tactile sensitivity) of the ground beneath our feet? Holowka *et al.*⁵ report on page 261 that thick patches of foot skin, termed calluses, do just that. The authors reached this conclusion by studying callus thickness and hardness, plus foot sensitivity, in individuals in Kenya and the United States who usually either wear shoes or go barefoot (Fig. 1).

Holowka and colleagues measured callus thickness using ultrasound. They report that people who were normally barefoot had calluses that were approximately 30% thicker than those of people who typically wore shoes. It could be assumed that thicker calluses provide more protection than thinner ones, all else being equal. But is all else indeed equal? To find out, the authors quantified the mechanical properties of foot soles using a device called a Shore durometer. This tool is commonly used in the footwear industry, and measures foot resistance to an indentation caused by the apparatus. The authors' results show that, compared with skin on the feet of those who normally wore shoes, the skin of barefoot individuals was approximately 30% harder. This thicker, harder skin presumably protects their feet just like a shoe's sole.

Our feet are remarkably sensitive, enabling pleasant sensations such as the feeling when walking barefoot on a beach, but also the experience of pain when stepping on a sharp rock. This sensitivity is useful because our body's nerves use such information to fine-tune our posture and gait, in a similar way to how our sensitive fingertips enable us to precisely manipulate objects. As part of the system that aids this tactile sensitivity, a variety of mechanoreceptors in our skin sense mechanical



Figure 1 | Villagers waiting to vote in Kenya. In this queue at a polling station, there are both barefoot and shod individuals. Holowka *et al.*⁵ studied people in Kenya and the United States who either are usually barefoot or usually wear shoes. The authors investigated whether the formation of thick patches of skin called calluses, which are usually thicker and harder in people who are normally barefoot than in shod individuals, affects foot sensitivity.

stimuli such as pressure. If these receptors don't work normally, as can occur in disease⁶ or during experimental manipulation⁷, people can have problems with their balance or gait⁸.

Using a device called a vibration exciter, Holowka and colleagues assessed the sensitivity of two types of mechanoreceptor, known as Meissner and Pacinian corpuscles, in their volunteers. These mechanoreceptors respond to high-frequency pressure stimulations (at 5–50 and 100–300 hertz, respectively) that occur when walking and running, especially when the foot strikes the ground. Holowka and colleagues' key discovery is probably unexpected, given that one might predict that a thick layer of skin would be a barrier to the transmission of stimuli: mechanoreceptor sensitivity is not lower in habitually barefoot people than in people who usually wear shoes.

Barefoot walking with thick calluses is our

biologically normal condition, and people who usually walk barefoot experience few problems doing so^{9,10}, as I have also observed in my research in India^{11,12}. Walkers who are habitually barefoot report no pain when walking on most terrains that shod walkers would find painful to walk on barefoot. However, habitually barefoot walkers might be at a higher risk of traumatic injury, given that shoes can offer better protection than can calluses¹³. Nevertheless, barefoot-walkers' feet might be generally healthier than those of habitually shod people⁹, and foot problems such as bunions and fallen arches are rare in people who seldom wear shoes.

Should we now bin our shoes? Well, maybe not. Shoes can help people who have foot conditions¹⁴, and can also boost athletic performance¹⁵. In everyday life, shoes can keep our feet warm, and offer more protection than calluses can. Therefore, what kind of shoes

ROBERTO SCHMIDT/APP/GETTY

we should wear becomes the more pressing question.

Holowka and colleagues argue that thick calluses preserve sensitivity because their hardness enables mechanical stimuli from the ground to be transmitted, with little dampening, to deep layers of the skin in which the key mechanoreceptors are located. If so, shoes with hard soles should be predicted to do the same job as calluses. Indeed, the hard-soled shoes used by drivers competing in Formula 1 races provide even greater than normal sensitivity at high frequencies of vibration¹⁶.

More research will be needed to fully understand the effect of shoe soles on gait. Humans are not like machines, in which just one variable at a time can be studied. Human movement is a complex, dynamic system, and changing even one variable, such as shoe-sole stiffness, will probably trigger other physiological and behavioural changes. For example, running when using cushioned soles, compared with running barefoot, triggers changes in how the foot makes contact with the ground (called the strike pattern)¹⁷, and also causes the arch of the foot to behave more stiffly¹⁸.

Holowka *et al.* conducted an experiment using a treadmill apparatus to quantify impact forces, which are the forces that the foot encounters immediately after it strikes the ground. They found that even if uncushioned shoes were used to mimic a callus-like sole, these shoes did not exactly mirror the effect of calluses during foot strike. Compared with their observations of unshod individuals, such footwear led to a slower rise in the impact force and a higher impulse (the product of the force and duration of the impact phase, which is when the foot hits the ground and slows abruptly).

It makes sense that preserving foot sensitivity is useful, especially if maintaining stability is challenging. This is true for gymnasts and also for older people, in whom faculties such as vision, balance and foot sensitivity decline naturally with age. Shoes with hard soles might therefore be a good idea for such individuals. Indeed, wearing hard-soled shoes can reduce the risk of older people falling¹⁹. Holowka and colleagues' work helps to explain why this is so. Although this mystery has been solved, much remains to be discovered about what affects how humans walk. ■

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PLANETARY SCIENCE

Low retention of impact material by the Moon

Simulations demonstrate that the Moon's ability to retain material from striking impactors is lower than was previously assumed. This finding helps to explain the scarcity of precious metals in the Moon relative to Earth. [SEE LETTER P.226](#)

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As a planetary body forms, precious metals, such as gold and iridium, are stripped from its rocky mantle and passed into its metallic core. Successive impacts with other objects then re-enrich the mantle in these elements — a process known as late accretion^{1,2}. Measurements of lunar rocks show that the Moon is greatly depleted in precious metals compared with Earth^{3,4}. This deficit implies that the ratio of mass added to Earth during late accretion compared with that added to the Moon is more than 1,000:1, which is substantially different from the predicted ratio⁵ of about 20:1. On page 226, Zhu *et al.*⁶ show that inefficient delivery of material from glancing impacts, combined with an early hot, molten stage on the Moon,

can explain this anomalous input-mass ratio.

An analysis of the mass and composition⁷ of material added to a planetary body can be used to examine the body's formation. Moreover, late accretion is linked to the delivery of water and other volatile elements to Earth⁸, and such additions are probably a key factor in our planet's habitability. The low abundances of precious metals in lunar rocks^{3,4,9} has prompted the proposal of competing models to explain the anomalous input-mass ratio between Earth and the Moon.

At one extreme, these models include delivery of material by a few massive impactors (larger than 2,500 kilometres in diameter) that preferentially struck Earth⁵. At the other, focusing of small objects (less than 10 m in diameter) on to Earth might have produced similar effects¹⁰. It has

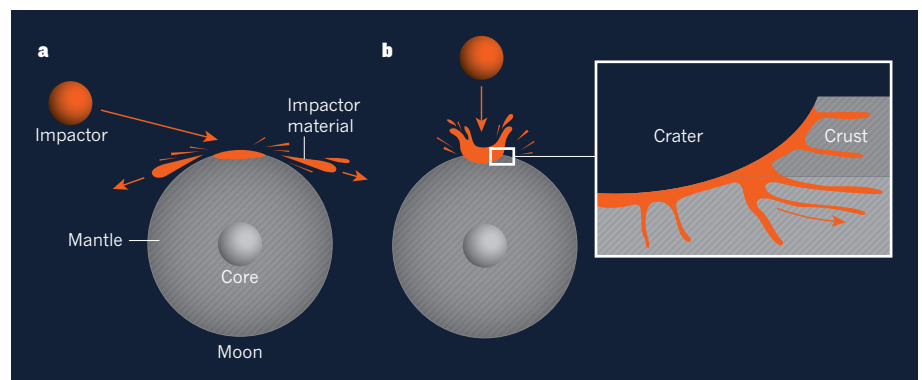


Figure 1 | Lunar glancing blows and direct hits. **a**, Zhu *et al.*⁶ show that the Moon's ability to retain material from an impactor depends on the angle of the impact with respect to the lunar surface. Low-angle impacts (glancing blows) can result in 80% of the impactor material being lost. The Moon's rocky mantle and metallic core are shown. **b**, By contrast, high-angle impacts (direct hits) lead to a substantial fraction of the impactor material being retained. After the impact (see inset), a crater forms, and the impactor material can be incorporated into both the lunar crust and mantle.