Characterising the foot pads of climbing mammals to inspire new climbing shoe designs

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Relatively little is known about how climbing shoe design influences performance. Early climbing shoes were based on mountaineering shoes, with adaptations - such as small hobnails inserted into the base - to increase grip with the substrate. From around the 1960s the sport started to gain popularity and the modern climbing shoe emerged [1,2]. Modern climbing shoes typically have a stiff, relatively smooth rubber sole, with no tread pattern. Through the use of a bio-inspired design process, there is potential to use patterns and strategies generated by nature and explore how they can be applied to create innovative climbing shoes. Indeed, we suggest that there is scope to compare the foot morphology of climbing mammals, including those with paws and hooves, and use this as inspiration for designing climbing shoes. Here, we present a case study that uses our observations of the natural world to propose novel candidate structures for climbing shoe design. There are many foot shapes and structures in mammals, which are associated with scansorial (or climbing) locomotion. For example, the presence of long deformable digits, and having many, textured, deformable foot pads can aid climbing [3,4]. Specifically, the convex shape, compliant nature and texture of foot pads can all improve grip during climbing [4]. While studies have described foot adaptations in some primates, rodents, and marsupials [5,6], there has been no formal, systematic description of climbing adaptations across mammalian species. As such, there is an opportunity to explore and describe foot pad adaptations in climbing mammals, with a view to inspiring climbing shoe design.

We applied a systematic approach to describe the foot morphology of mammalian climbing species. So far, we have photographed and categorised the feet of two-hundred and fifteen mammalian species using the skins collections at Liverpool World Museum and National Museums Scotland. From these images, we have described the location, shape, size, and texture of foot pads. Figure 1 shows the variation of pad arrangement and number in a variety of climbing mammals. Indeed, we have found that the feet of climbing mammals are diverse. They can vary in digit number (4-5), pad number (1-15), pad texture (horizontal grooved, irregular, smooth, and circles,), the presence (or absence) of claws or hooves. Overall, we have observed that deformable and textured foot pads are common across climbing mammals, whereas the climbing shoe is typically stiff with little to no texture.

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Figure 1: A selection of varied paw specimens (scale bar 10mm), a) Gray slender loris i.e., *Loris tardigradus nordicus*, b) Koala i.e., *Phascolarctos cinereus*, c) South american coati i.e., *Nasua nasua*, d) Ring-tailed lemur i.e., *Lemur catta*, e) Least weasel i.e., *Mustela nivalis*, f) Macaque i.e., *Macaca sp*., g) Gambian sun squirrel i.e., *Helioscirus gambianus* h) Himalayan marmot i.e., *Marmota himalayana*

Within this presentation, we will compare the foot pad morphology of rock climbing and tree climbing mammals using multivariate phylogenetic analyses. We will also use principal component analysis and cluster analyses to group foot morphotypes associated with tree and rock climbing in mammals. These analyses will be used to identify candidate structures to inspire future climbing shoe sole designs, which will be developed using established techniques, such as needs analysis.

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