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Arched footprints preserve the motions of fossil hominin feet

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Supplementary Information for

Arched footprints preserve the motions of fossil hominin feet

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Supplementary Notes (Supplementary Notes 1-3)

Supplementary Note 1. Relationship between track RAV and navicular height

While studying the relationship between track RAV and foot arch morphology, we also explored the correlation between track RAV and navicular height. We did not have navicular height measurements available from our biplanar X-ray experiments, but we were able to collect requisite data from previously published experiments[17]. Briefly, these data include caliper measurements of navicular height and tape measurements of foot length during quiet standing, and photogrammetric 3D models of footprints that those subjects created in hydrated mud at self-selected comfortable walking speeds. Full details of the experiments are published elsewhere[17].

These experimental tracks (n = 54 tracks produced by 18 subjects [each subject produced 3 tracks]; Supplementary Data 5) were made across varying levels of substrate hydration and compliance, and we observed a very strong positive correlation between track RAV and footprint depth (Spearman's $\rho = 0.88$, $p < 2.2*10^{-6}$). This provides further support for the pattern observed in Fig. 1H, where the same foot produces tracks with higher RAVs when walking on more compliant substrates. In order to evaluate potential relationships between track and foot arch morphology, without depth-related trends obscuring those trends, we restricted the sample to tracks within 2 standard deviations of the mean depth observed in deep tracks ("wet 2.5" and "wet 5" conditions) in our biplanar X-ray experiments, just as we did for fossil footprint comparisons. In this sample filtered by depth (n = 28 tracks produced by 12 subjects), we found that the correlation between track RAV and relative navicular height (navicular height/foot length) was not statistically significant (Spearman's $\rho = -0.28$; $p = 0.15$; Extended Data Fig. 1). This result further demonstrates that the longitudinal arches of tracks do not resemble the longitudinal arches of the feet that made them.

Supplementary Note 2. Origins of hypotheses connecting foot kinematics to track arch morphology

In our initial steps to explore foot kinematics during track formation, we used Maya's "Create animation snapshot" tool to visualize the composite 3-D volume that was swept by the foot while it passed through deformable substrates. These visualizations (Extended Data Fig. 2) revealed similarity between the 'longitudinal arch' created by the foot's volumetric sweep and the arch morphology that was left behind in the resulting track. This realization led us to further investigate the kinematic origins of track arch morphology through particle simulation. In that latter context we were subsequently able to directly observe and understand the kinematic drivers of arch ontogeny during track formation.

Supplementary Note 3. Arches of chimpanzee tracks

Tracks produced by chimpanzees walking bipedally showed highly variable RAV measurements, irrespective of track depth (Fig. 4A). In some cases their RAVs fell within the distribution of measurements from Laetoli hominin tracks, and a few even approached values measured from experimental human tracks. However, it is important to recognize that despite similarity in RAV, arch morphology in these tracks is very different from that observed in all other samples. Those chimpanzee tracks with the highest RAV measurements included a concentration of sediment in between the impressions produced by the hallux and the lateral forefoot, a product of the hallux being positioned in a widely divergent posture during those trials. Because the concentration of sediment fell in between the first and fifth metatarsal heads, it was captured by the prism used to measure RAV. This arch morphology is easily distinguished from the modern human and fossil hominin tracks, in which sediment was instead concentrated beneath the medial midfoot to form a longitudinal arch (Extended Data Fig. 3).

It is important to note that chimpanzee tracks still had lower RAVs for their depth than the modern human experimental tracks (Fig. 4A). However, the fact that some differences in gross footprint morphology are not captured by RAV should be noted by future users of this measurement approach. Despite the clear inferential value of RAV for tracks made by human-like feet, caution should be exercised when applying this measure to tracks made by significantly different foot morphologies such as chimpanzees who can produce an "arched" track (i.e., one with a non-zero RAV) for different reasons than heel-sole-toe foot kinematics.