



Original article

# Foot strike patterns and hind limb joint angles during running in Hadza hunter-gatherers

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## Abstract

**Background:** Investigations of running gait among barefoot and populations have revealed a diversity of foot strike behaviors, with some preferentially employing a rearfoot strike (RFS) as the foot touches down while others employ a midfoot strike (MFS) or forefoot strike (FFS). Here, we report foot strike behavior and joint angles among traditional Hadza hunter-gatherers living in Northern Tanzania.

**Methods:** Hadza adults ( $n = 26$ ) and juveniles ( $n = 14$ ) ran at a range of speeds (adults: mean  $3.4 \pm 0.7$  m/s, juveniles: mean  $3.2 \pm 0.5$  m/s) over an outdoor trackway while being recorded via high-speed digital video. Foot strike type (RFS, MFS, or FFS) and hind limb segment angles at foot strike were recorded.

**Results:** Hadza men preferentially employed MFS (86.7% of men), while Hadza women and juveniles preferentially employed RFS (90.9% and 85.7% of women and juveniles, respectively). No FFS was recorded. Speed, the presence of footwear (sandals vs. barefoot), and trial duration had no effect on foot strike type.

**Conclusion:** Unlike other habitually barefoot populations which prefer FFS while running, Hadza men preferred MFS, and Hadza women and juveniles preferred RFS. Sex and age differences in foot strike behavior among Hadza adults may reflect differences in running experience, with men learning to prefer MFS as they accumulate more running experience.

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**Keywords:** Barefoot; Biomechanics; Foot strike; Foraging; Running

## 1. Introduction

Like many other animals, humans employ a bouncing, mass-spring gait when running, with the hind limb storing and releasing elastic strain energy each step.<sup>1,2</sup> This spring-like behavior of the lower limb reduces the amount of muscle work required and improves running efficiency.<sup>1–3</sup> From a mechanical perspective, the two most important anatomical springs in the human leg are the Achilles tendon and the

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plantar arch; together, these structures store and return roughly half of the potential and kinetic energy lost each step during running.<sup>1</sup> These anatomical springs are most effective when runners land on the middle or front of the foot, allowing the Achilles tendon and plantar arch to stretch as the foot is loaded during early stance phase.<sup>4</sup> Landing on the midfoot or forefoot may also reduce the incidence of running-related injuries.<sup>5</sup> Nonetheless, many runners habitually heel strike,<sup>6–8</sup> landing on the rear portion of their foot, and the effects of training, footwear, and speed on foot strike patterns remain unclear. Here, we examine running mechanics among Hadza hunter-gatherers to assess foot strike patterns in an untrained, physically active, traditional population with minimal footwear.

Foot strike patterns have recently emerged in debates over the role of endurance running in human evolution. Endurance running has been cited by several researchers as a critical adaptation in the hominin lineage, marking a departure away from an ape-like, plant-based foraging ecology and toward a more active, omnivorous ecological strategy that included scavenging and hunting.<sup>9–11</sup> Bramble and Lieberman<sup>11</sup> noted that many of the anatomical features associated with effective endurance running in modern humans first appear in *Homo erectus* and proposed that key evolutionary changes seen in our genus followed the evolution of endurance running. Selection for endurance may have even played a critical role in the evolution of increased brain size.<sup>12</sup>

Subsequent work by Lieberman and colleagues<sup>6</sup> has suggested that the anatomical adaptations in the human foot are particularly advantageous during unshod running with a forefoot or midfoot strike (FFS, MFS). In a study of habitually barefoot Kenyan runners from the Kalenjin population, Lieberman and colleagues<sup>6</sup> noted that these renowned endurance runners tend to land on the front or middle of their foot while running. In contrast, habitually shod American runners tend to rearfoot strike (RFS). Lieberman and colleagues<sup>6</sup> hypothesized that the population difference in foot strike behavior was influenced by differences in footwear: barefoot running, common among Kalenjin individuals, allows runners to experience the high impact forces imparted by RFS and leads to the adoption of MFS or FFS. In contrast, conventional running shoes absorb much of the impact associated with RFS, and their elevated heel increases the likelihood and incidence of RFS. This hypothesis suggests that RFS has become more common with the development and popularity of modern athletic footwear, and that RFS should be rare or absent among unshod or minimally shod populations.

More recently, Hatala and colleagues<sup>8</sup> studied foot strike and impact forces at different running speeds in 38 habitually unshod adults from the Daasanach population of Northern Kenya. The Daasanach are traditional pastoralists; they typically walk long distances to tend herds, gather water, and in other daily tasks, but run much less than the Kalenjin. In contrast to the Kalenjin, Hatala and colleagues<sup>8</sup> found that the Daasanach often RFS, and that running speed affects foot strike behavior. At speeds less than 5.01 m/s, the Daasanach used RFS at a higher frequency than MFS or FFS. Between

5.01 and 6 m/s, frequencies of MFS and FFS were similar, while MFS was the predominant pattern at speeds greater than 6.01 m/s. These results indicate that not all unshod populations prefer to MFS or FFS while running, and that training, experience, and speed may affect foot strike patterns.

Yet another pattern of foot strike use is reported for the Tarahumara, a minimally shod population of traditional farmers living in the Sierra Madre Occidental of Northwestern Mexico.<sup>13</sup> The Tarahumara are renowned endurance runners, running 75 km or more in traditional ball games and, in recent years, competing in ultramarathons.<sup>14</sup> Tarahumara traditionally wore simple rawhide sandals (*huaraches*), and many continue to do so today, although some have adopted conventional running shoes.<sup>13</sup> Lieberman<sup>13</sup> reported that 89% of Tarahumara who wear conventional shoes habitually RFS, while Tarahumara who wear traditional *huaraches* tend to MFS or FFS.

In this study we examined foot strike patterns and running kinematics among traditional Hadza hunter-gatherers in Northern Tanzania. As described in detail elsewhere,<sup>15</sup> traditional Hadza subsist almost entirely on wild foods, hunting and gathering each day on foot and with simple hand tools. Traditional Hadza have no agriculture, livestock, or machinery. Women typically walk 6 km each day gathering wild berries, tubers, and other plant foods, while men walk an average of 11 km per day, hunting small and large game with bow and arrow, and gathering honey.<sup>15,16</sup> The landscape they inhabit is semiarid savannah with a patchy mix of forest and grassland cover; the ground is often rocky, and low craggy hills are common. While the Hadza are highly active, they rarely run.<sup>15</sup>

Musiba and colleagues<sup>17</sup> conducted a study of walking gait and foot dimensions among traditional Hadza. As discussed in that report, Hadza adults typically wear simple sandals made from repurposed tire rubber, common throughout East Africa. These sandals have relatively thin (~1 cm) soles that offer protection from sharp rocks and thorny plants but do not provide any cushioning or elevate the heel. Traditional Hadza can therefore be categorized accurately as “minimally shod”, and their feet display many of the same features (e.g., splayed toes, greater foot width) evident in habitually unshod populations.<sup>17,18</sup> While Musiba and colleagues<sup>17</sup> did not examine running, self-selected speeds during walking trials reported for Hadza adults (1.15 m/s) were relatively fast compared to other traditional, unshod populations, and the Hadza also used greater stride frequencies and stride lengths.

We used high-speed digital video to analyze foot strike patterns and limb-segment angles of Hadza adults and juveniles running at a range of speeds. Our objectives were to determine the frequency of RFS, MFS, and FFS among the Hadza, to investigate the effects of speed and age on foot strike patterns, and to compare these data to published values for the Kalenjin and Daasanach. We predicted that the Hadza, who lack the training and experience in endurance running common among the Kalenjin, would exhibit foot strike patterns more similar to the Daasanach.

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