

ETIOLOGY and FUNCTIONAL IMPLICATIONS of HALLUX ANGLE

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INTRODUCTION

Do modern (i.e. tapering) shoes have significant morphological effects on the foot, and in turn on biomechanics and performance? As early as the 1950s, Barnicot reported, “Current opinion favours the effect of constricting footwear as a major cause of the deformity, and this view is supported by common-sense and observation alike.”

The following is a report on published literature in this area.

Here, I review several publications that address these questions:

1. Are there differences in hallux angle between shod and unshod populations?
2. Do hallux angle differences have biomechanical consequences?
3. Do hallux angle differences have health or athletic performance consequences?

STUDIES

Foot Morphological Difference between Habitually Shod and Unshod Runners

In a 2015 retrospective cross sectional study, Shu et al. compare foot morphologies of 196 habitually shod runners (130m, 66f) and 168 habitually unshod runners (90m, 78f) using a three-dimensional foot scanning system. They report significant morphological differences in foot length, width, hallux angle, and distance between hallux and toes between the two groups ($p=0.001$ in all categories). Habitually shod runners were found to have significantly narrower feet, a steeper valgus angle of the hallux, a smaller distance between hallux and toe, and longer feet than had the habitually unshod runners.



Fig 1
2D foot print image of habitually shod (left) and unshod (right) runners.

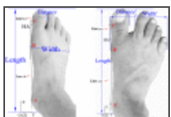


Fig 2
The dorsal view of foot surface data, length (length'), width (width'), minimal distance (distance') and HA (hallux angle, HA').

The position of the hallux in West Africans

In a 1955 retrospective cross sectional study, Barnicot & Hardy measured the hallux position of 652 Nigerian subjects (325f, 327m), mainly of the Yoruba tribe, and 133 European subjects (66m, 68f). The European sample was mostly university students, habitually shod. Of the Nigerian subjects, 113 were soldiers who in fact wore boots, while most were habitually unshod.

Footprints were made using a Scholl Pedograph, a thin rubber membrane which is inked on its lower surface and is stepped on to make a footprint on paper below.

A significant difference in the mean hallux angle of Europeans (shod) and Nigerians (unshod) was found. There was an absence of difference in hallux angle between the sexes in the unshod Nigerian population, while the shod European population demonstrated significant difference in hallux angle between males and females. A significant difference in distance between hallux and second toe was found between 76 habitually unshod Nigerian schoolgirls and habitually shod 66 European females, with the Nigerian average at 6.9mm compared to 4.9mm for Europeans.

RESULTS

Table 1. *Male subjects*

Sample	No.	Mean hallux angle	S.D.	Mean age (years)	S.D.
1. Europeans	66	+6.9°	5.3°	25.9	7.8
2. Nigerian soldiers	113	+2.2°	7.2°	—	—
3. Nigerians—25 years and older	108	+1.1°	6.8°	49.9	14.0
4. Nigerians below 25 years	106	+2.3°	5.8°	16.2	3.6
5. Nigerians—2 and 3 pooled.	221	+1.7°	7.0°	—	—
6. Total Nigerian males	327	+1.88°	6.6°	—	—

Table 2. *Female subjects*

Sample	No.	Mean hallux angle	S.D.	Mean age (years)	S.D.
1. Europeans	68	+11.0°	5.1°	21.4	3.3
2. Europeans (morbid group. Hallux valgus)	84	+21.9°	7.0	—	—
3. Nigerians—25 years and older	148	−0.03°	7.2°	45.5	9.8
4. Nigerians below 25 years	177	+0.49°	5.8°	15.5	2.7
5. Nigerians below 18 years—shoeless	120	+0.18°	6.1°	—	—
6. Nigerians below 18 years—shoes	53	+1.36°	5.1°	—	—
7. Total Nigerian females	325	+0.24°	6.5°	—	—

Foot strike patterns and collision forces in habitually barefoot versus shod runners.

In a 2010 retrospective, cross-sectional study published in *Nature*, Lieberman et al. compare foot-strike kinematics of five groups of endurance runners, who all run at least 20km/week. They demonstrate that habitually unshod endurance runners and shod runners who grew up habitually unshod, most often land with a fore-foot strike, compared to habitually shod endurance runners who grew up habitually shod, who most often land with a heel-strike.

They compared five groups: (G1) 8 habitually shod athletes from the US; (G2) 14 athletes from the Rift Valley in Kenya who grew up barefoot but now wear sneakers; (G3) 8 US runners who grew up shod but now habitually run barefoot or minimally; and two groups of adolescents from the Rift Valley; (G4) 16 teens who've never worn shoes; and (G5) 16 urban teens who've grown up shod.

G1 and G5 were found to run mostly with rear-foot strike. Runners who grew up barefoot or switched to barefoot running predominantly run with a fore-foot strike, whether unshod or shod.

US subjects were measured on ground-embedded pressure plates in 20-25m tracks, and were captured by a three-dimensional infra-red kinematic system (Qualysis) and on video. African subjects were measured on ground-embedded pressure sensors in 20-25m tracks and on video.

Magnitudes of peak vertical force are found to be three times lower in habitually unshod runners who fore-foot striker than in habitually shod runners who rear-foot strike. Rates of loading in fore-foot strikers were found to be approximately half that of rear-foot strikers.

Table 1 | Foot strike type and joint angles of habitual barefoot and shod runners from Kenya and the USA

Group	N (male/female)	Age (age shod) (yr)	Strike-type mode (%)*				Joint angle at foot strike			Speed (m s ⁻¹)
			Condition	RFS	MFS	FFS	Plantar foot†	Ankle†	Knee	
(1) Habitually shod adults, USA‡	8 (6/2)	19.1 ± 0.4 (<2)	Barefoot	83	17	0	-16.4 ± 4.4°	0.2 ± 3.0°	12.1 ± 7.9°	4.0 ± 0.3
			Shod	100	0	0	-28.3 ± 6.2°	-9.3 ± 6.5°	9.1 ± 6.4°	4.2 ± 0.3
(2) Recently shod adults, Kenya	14 (13/1)	23.1 ± 3.5 (12.4 ± 5.6)	Barefoot	9	0	91	3.7 ± 9.8°	18.6 ± 7.7°	21.2 ± 4.4°	5.9 ± 0.6
			Shod	29	18	54	-1.8 ± 7.4°	15.0 ± 6.7°	22.2 ± 4.3°	5.7 ± 0.6
(3) Habitually barefoot adults, USA§	8 (7/1)	38.3 ± 8.9 (<2)	Barefoot	25	0	75	8.4 ± 4.4°	17.6 ± 5.8°	17.3 ± 2.5°	3.9 ± 0.4
			Shod	50	13	37	-2.2 ± 14.0°	8.1 ± 15.9°	16.6 ± 2.4°	4.0 ± 0.3
(4) Barefoot adolescents, Kenya	16 (8/8)	13.5 ± 1.4 (never)	Barefoot	12	22	66	1.13 ± 6.8°	14.6 ± 8.3°	22.8 ± 5.4°	5.5 ± 0.5
			Shod	—	—	—	—	—	—	—
(5) Shod adolescents, Kenya	17 (10/7)	15.0 ± 0.8 (<5)	Barefoot	62	19	19	-10.1 ± 9.7°	4.1 ± 10.9°	18.9 ± 6.5°	5.1 ± 0.5
			Shod	97	3	0	-19.8 ± 10.3°	-2.7 ± 9.0°	18.4 ± 6.6°	4.9 ± 0.5

Vertical compliance (drop in body's center of mass relative to the vertical force during the period of impact) was found to be greater in fore-foot strike running than in rear-foot strike running.

Functional impairments characterizing mild, moderate, and severe hallux valgus.

In a 2015 retrospective, cross-sectional study, Hurn et al. examined sixty adults with hallux valgus (7 men, 53 women) and 30 control subjects (5 men, 25 women). Hallux valgus is here classified by intensity as mild, moderate and severe and is defined as “progressive lateral deviation of the hallux, first metatarsophalangeal joint subluxation, and development of osteoarthritis.”

Subjects were given hallux valgus assessments and measured for foot posture and mobility (FPI-6), hallux plantar flexion and strength (isolated isometric hallux contractions on load cell grid), plantar pressures (in-shoe plantar pressure with Plantar-X System), timed walking (as fast as they could on 10m walkway), postural sway (force plate).

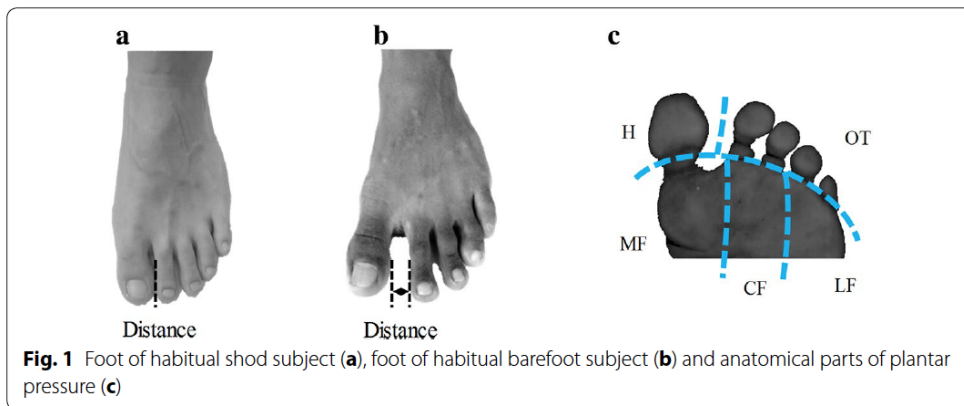
This study enrolled sixty adults with hallux valgus (classified as mild, moderate, and severe on dorsal-plantar radiographs) and 30 control subjects. Measures included hallux plantar flexion and abduction strength, walking performance, postural sway, and forefoot plantar pressures. Statistical analyses consisted of pairwise comparisons to investigate differences between groups, adjusting for age, sex, body mass index, and foot pain.

Hallux plantar flexion and abduction strength were found to be significantly lower in subjects with moderate and severe hallux valgus, compared to the control group (p=0.001). Subjects with moderate to severe hallux valgus showed significantly lower hallux peak pressure and pressure-time than did the control group (p=0.001). Subjects with severe hallux valgus showed higher medio-lateral postural sway than did the control group (p=0.01).

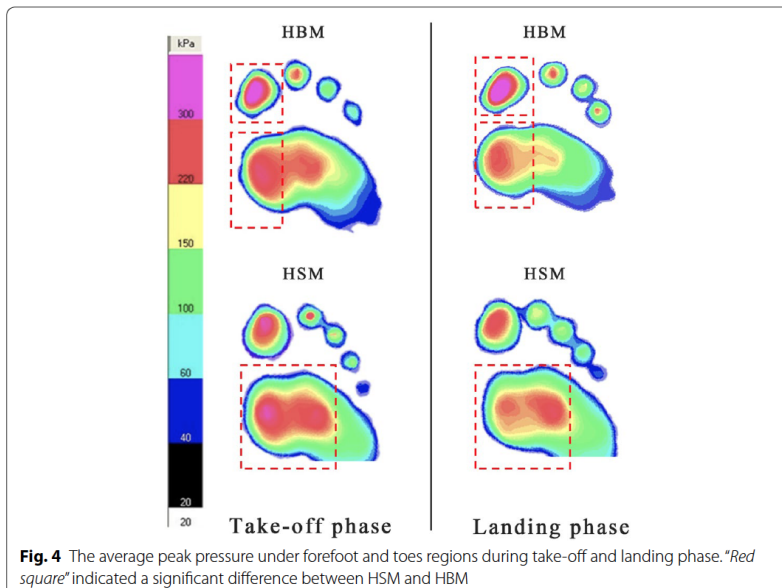
Dynamic loading and kinematic analysis of vertical jump based on different forefoot morphology.

In a 2016 retrospective, cross-sectional study, Shu et al. examined whether there are differences in measured ankle motion and plantar pressure during vertical jumping in 18 habitually barefoot males (from South India) and 20 habitually shod males (Chinese). All subjects were students of Ningbo University who volunteered for the study. “Easy-Foot-Scan” was used to record morphological data, and significant differences in hallux-to-toe distance were found. Three-dimensional kinematic data was collected from the Vicon motion analysis system, and plantar pressure and ankle kinematics were measured during vertical jumping on an EMED force platform.

Morphological differences between habitually shod males and habitually barefoot males were significant regarding distance between hallux and second toe, which was larger in HBM (see figure below).



Significant differences in ankle joints were seen between HBM and HSM during the take-off and landing phases of vertical jumping. During vertical jumping, habitually shod males showed larger plantar loading under hallux and forefoot, while habitually barefoot males demonstrated smaller degrees of ankle plantarflexion, eversion, and external rotation than habitually shod males.



No significant difference in jump height was found, suggesting that height of jump may be more dependent on leg and core strength than on foot morphology.

In summary, the distance between hallux and other toes in HBM was greater than in HSM. HBM showed larger plantar loading under hallux and medial forefoot, while HSM showed larger plantar loading under medial and central forefoot. HBM had smaller ankle plantarflexion, eversion and external rotation than HSM.

These results support the model that habitual shoddedness results not only in anatomic change, but that these changes translate to different biomechanical consequences (different loading stresses).

DISCUSSION

As noted in the introduction, I examined 3 questions:

1. Are there differences in hallux between shod and unshod populations?
2. Do hallux differences have biomechanical consequences?
3. Do hallux differences have health or athletic performance consequences?

CONSISTENCY

Results from these studies are remarkably consistent. Shu (2015, 2016) and Barnicot (1955), show larger distance between hallux and second toe, and smaller valgus angle in habitually unshod populations. Leiberman (2010) and Shu (2016) both show performance differences along shod and unshod population lines. Hurn (2015) and Shu (2016) both show functional differences along shod and unshod population lines.

DESIGN DIFFERENCES

Hurn and Shu define hallux valgus differently, with Shu eliminating subjects for *having* hallux valgus, though not providing an explanation for how he differentiates them from other people whose hallux is at a valgus angle of more than 1 degree. Meanwhile, Hurn defines hallux valgus as “characterized by progressive lateral deviation of the hallux, first metatarsophalangeal joint subluxation, and development of osteoarthritis,” and classifies it on a spectrum of mild, moderate and severe.

SURPRISES

Barnicot finds almost no difference in hallux angle between unshod Nigerian youth and adults. This is a novel finding which is strongly suggestive of shoe wearing and shoe shape being a contributing factor in the development of hallux valgus.

CRITIQUES / ISSUES

Shu’s 2015 morphological study problematically excluded people with “foot deformities such as hallux valgus” without defining hallux valgus as it differs from any inward angling of the hallux. At what threshold does one cross over from having a slightly valgus hallux to having the clinical condition “hallux valgus”? In addition to defining their parameters for this condition, I would like the authors to have shown the data with and without this eliminated group, as it seems to be spectrally related, especially if hallux valgus is etiologically related to shoe shape.

The observed groups are divided by ethnicity as well as by the independent variable “shod or unshod”. The shod runners were Chinese, while the unshod runners were Indian. This potentially muddles data, and suggests a need for replication of the study within a more homogenous population.

Hurn’s study is possibly flawed for the volunteer status of the participants. Maybe those who volunteered are people who experience functional impairments from their hallux valgus in their daily life and hope to find relief by getting involved in a cutting edge study... There may be people out there with severe hallux valgus who suffer no functional impairment and they didn’t bother to volunteer for the study. A larger study needs to be done with recruited subjects to account for volunteer motives.

The Barnicot study could have been more precise if it had used X-ray evaluation instead of a Scholl Pedograph. They also would have done well not to include shod soldiers in their unshod population, as this is inconsistent, and indicates their gaze toward ethnic or national categorical differences rather than habitual differences.

Leiberman’s numbers are very small; his study requires replication with larger populations.

CONCLUSIONS

Prospective longitudinal studies are conspicuously lacking in this literature. They would be helpful in determining environmental aspects of the etiology of hallux valgus. For example, two groups of children, shod and unshod, followed with regular check-ins for morphological imaging and hallux plantarflexion strength testing measured for fifty years, with shoe-wearing habits reported.

More immediately, hallux plantarflexion strength tests used by Hurn in hallux valgus populations could be interesting if used to compare habitually unshod and habitually shod populations.

This is a fascinating area of contemporary health studies that could have major implications for footwear design (athletic and everyday) and for sport. More studies are warranted, but the evidence so far is consistent and motivates more and better-designed studies. Particularly, more needs to be known about shoe shape (in plan and section) and its effect on hallux angle with habitual wearing, as living unshod is not an option for most people in the industrialized world.

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