From footprint morphometrics to the stature of fossil hominins: experimental regressions and uncertainties

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Jérémy Duveau[1,2]

[1]DFG Center for Advanced Studies "Words, Bones, Genes, Tools: Tracking Linguistic, Cultural and Biological Trajectories of the Human Past", Eberhard Karls University of Tübingen, Tübingen, Germany.
[2]UMR 7194 Histoire Naturelle de l'Homme Préhistorique, CNRS, Muséum National d'Histoire Naturelle, Université Perpignan Via Domitia, Paris, France

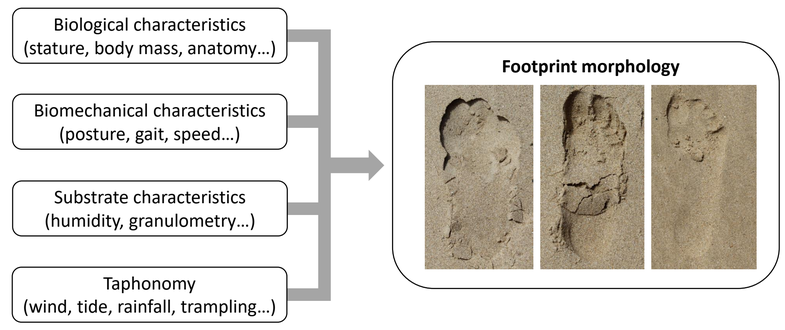
I- Introduction

Stature is one of the most used characteristics in paleoanthropology. Commonly inferred from long bones, it can also be estimated from footprints. It is usually estimated from footprint length by using the well-known foot length to stature ratio (14-16%). However, the morphology of the footprints is not only impacted by the dimensions of the foot but also by the biomechanical features of the individuals, the nature of the substrate in which they were left and taphonomic agents. Therefore, it is necessary to know the relationships between individual stature and footprint morphometry and not just foot morphometry. This poster presents a morphometric study performed on experimental footprints left in a dune environment, a common context in the fossil record.

Issues & objectives

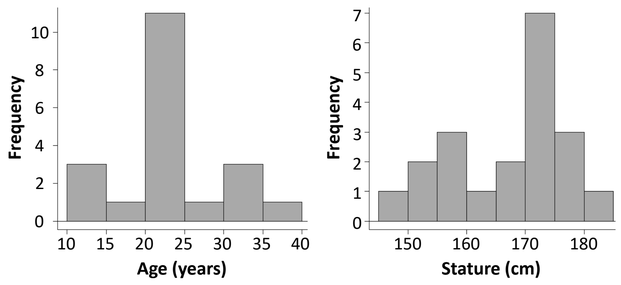
What are the relationships between footprint morphometrics and stature?
- Use the most appropriate variable to best estimate the stature of an individual

For each variable, what is the intraindividual variation?
- Quantify uncertainties to better estimate stature from isolated footprints.



II Material

- This study is based on the morphometric study of **175 experimental footprints** made by **20 individuals**.
- The age (11-36 years old) of each participant was recorded and their stature (146-182 cm) was measured.



Age and stature distributions of participants

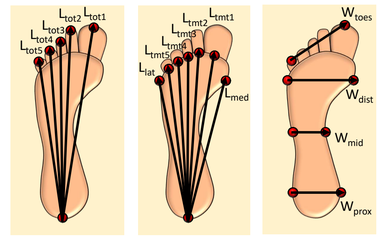
Experimental area and footprints (black scale bar: 2 cm)

- Each individual left footprints by walking on an experimental area composed of wet sand (fine to medium granulometry) from a dune environment.
- Each footprint was photographed, described and measured in situ .
- 49 footprints were digitized in 3D by photogrammetry in order to control the in situ measurements and to measure surfaces and volumes.

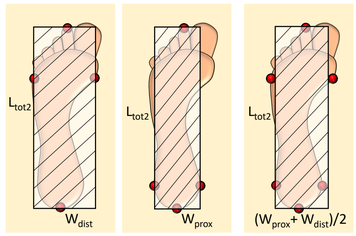
III Methodological approach

The morphometric study is based on **24 variables** measured on the 175 experimental footprints. The use of variables other than length is uncommon, but provides guidance for researchers wishing to estimate stature from incomplete footprints for which length is no longer measurable.

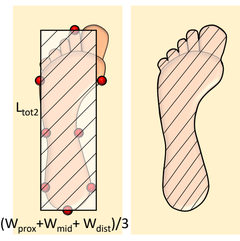
- **16 linear dimensions:**
  - 12 lengths
  - 4 widths
- **5 areas:**
  - 4 areas determined from linear dimensions
  - Area 5: accurate area determined on 3D models
- **3 volumes** determined from the 3D models:
  - Volume 1: heel maximum depth x Area 5
  - Volume 2: forefoot maximum depth x Area 5
  - Volume 3: accurate volume determined on 3D models



Linear dimensions



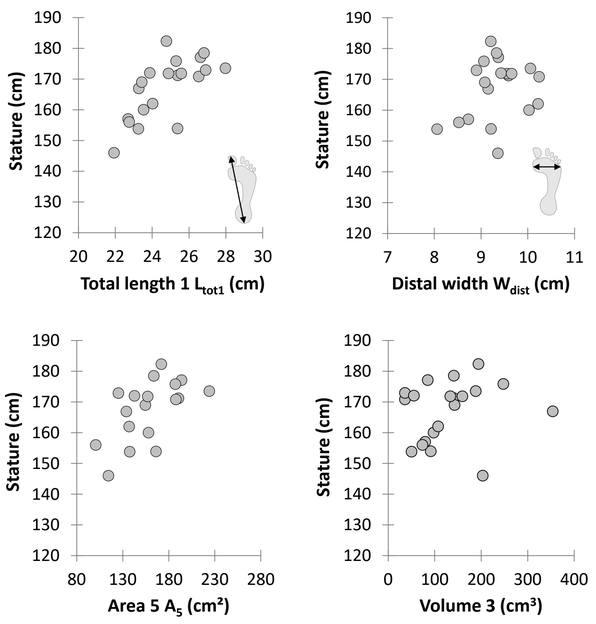
Area 1 *Area 2* *Area 3*



Area 4 *Area 5*

IV From footprint morphometrics to stature

- **Methods:** The relationship between stature and each mean morphometric variable was investigated by determining the Pearson correlation coefficient and the linear regression equation giving the best prediction.
- **Results:** Total and tarsometatarsal lengths, especially those associated with the first three toes, are the variables giving the best predictions. Widths, surfaces, but especially volumes have a much lower correlation.

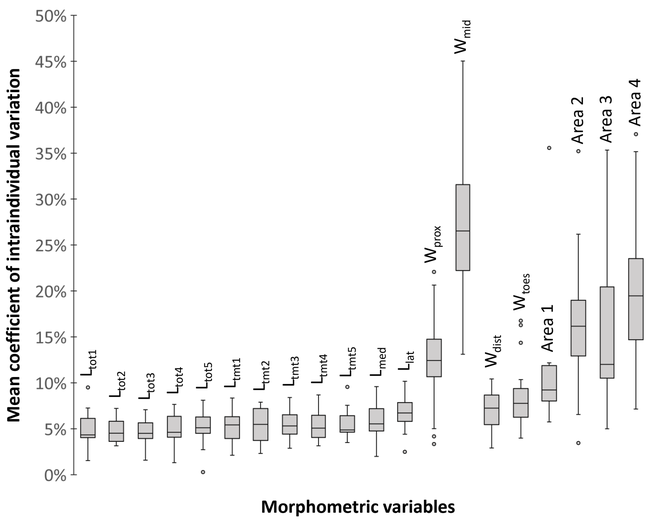


Morphometric variables (x)	Pearson correlation coefficient (r)	Linear equation for estimating stature (y)
L_{tot1} (cm)	0.69	y = 4.1x + 66.9
L_{tot2} (cm)	0.69	y = 4.1x + 67.6
L_{tot3} (cm)	0.69	y = 4.5x + 62.5
L_{tot4} (cm)	0.68	y = 4.6x + 66.5
L_{tot5} (cm)	0.65	y = 4.8x + 70.1
L_{tmt1} (cm)	0.70	y = 4.8x + 70.6
L_{tmt2} (cm)	0.69	y = 4.5x + 72.5
L_{tmt3} (cm)	0.70	y = 4.5x + 75.8
L_{tmt4} (cm)	0.66	y = 4.3x + 83.1
L_{tmt5} (cm)	0.64	y = 4.5x + 85.6
L_{med} (cm)	0.62	y = 5.6x + 67.2
L_{lat} (cm)	0.65	y = 5.9x + 68.2
W_{prox} (cm)	0.53	y = 10.3x + 103.7
W_{mid} (cm)	0.39	y = 3.2x +153.6
W_{dist} (cm)	0.28	y = 4.9x + 121.4
W_{toes} (cm)	0.64	y = 9.6x + 78.9
Area 1 (cm²)	0.39	y = 0.1x + 142.2
Area 2 (cm²)	0.56	y = 0.2x + 133.7
Area 3 (cm²)	0.48	y = 0.2x + 135.8
Area 4 (cm²)	0.52	y = 0.2x + 138.5
Area 5 (cm²)	0.59	y = 0.2x +137.9
Volume 1 (cm³)	0.30	y = 0.01x + 165.6
Volume 2 (cm³)	0.35	y = 0.04x + 159.8
Volume 3 (cm³)	0.17	y = 0.02x + 164.4

V Intraindividual variation

- **Methods:** The intraindividual variation was studied for each individual and each variable by calculating the average coefficient of variation and the maximum deviation from the individual mean. They have not been calculated for Area 5 and the 3 volumes, the 3D models from which they have been determined are too few.
- **Results:** Lengths are the variables with the least intraindividual variation. They are therefore the variables for which there will be the least uncertainties when estimating stature from an isolated footprint. The widths but especially the areas have much larger intra-individual variations.

Morphometric variables	Mean coefficient of variation (%)	Maximum deviation from the mean (%)
L_{tot1} (cm)	4.9%	16.9%
L_{tot2} (cm)	4.8%	13.4%
L_{tot3} (cm)	4.8%	14.6%
L_{tot4} (cm)	4.9%	14.0%
L_{tot5} (cm)	5.1%	16.5%
L_{tmt1} (cm)	5.3%	18.9%
L_{tmt2} (cm)	5.4%	15.3%
L_{tmt3} (cm)	5.5%	15.0%
L_{tmt4} (cm)	5.2%	15.9%
L_{tmt5} (cm)	5.4%	21.4%
L_{med} (cm)	5.8%	18.1%
L_{lat} (cm)	6.8%	15.3%
W_{prox} (cm)	12.5%	38.0%
W_{mid} (cm)	28.4%	92.3%
W_{dist} (cm)	7.1%	20.7%
W_{toes} (cm)	8.5%	34.4%
Area 1 (cm²)	10.7%	86.2%
Area 2 (cm²)	16.5%	85.8%
Area 3 (cm²)	15.2%	86.1%
Area 4 (cm²)	19.9%	87.4%



VI Discussion & Conclusion

This study shows that footprint lengths, particularly those between the base of the heel and the tips of the first three toes, are the morphometric variables of footprints that best predict stature. However, even these lengths are subject to significant uncertainties, not only residual errors in the regressions but also uncertainties related to intraindividual variation. This intraindividual variation is particularly important when estimating stature on isolated footprints, where the differences with the real stature of the individuals can be significant (≈15% for the estimates based on footprint lengths).

In addition to these residual errors in the regressions and to the intraindividual variation, there is a third uncertainty linked to variations in body proportions between the different hominin species. Like other body proportions (intermembral index, crural index…), the foot length to stature ratio may have varied during human evolution which would impact the estimation of stature from footprints. However, the fossil record is too fragmentary to directly and accurately quantify this ratio for any species other than *Homo sapiens*, including the well-known Neandertals.

Ardipithecus ramidus *Australopithecus afarensis* *Homo ergaster*

More information about this research?

If you want to learn more about this experimental study, it is detailed in an article that will be published in *L'Anthropologie* in October 2022.

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