University of Zagreb

3D SURFACE MODELS AND GEOMETRIC MORPHOMETRIC ANALYSIS OF FEMALE FEET

Doctoral Dissertation Defence

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Zagreb, September 05, 2013

University of Zagreb

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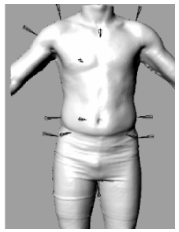
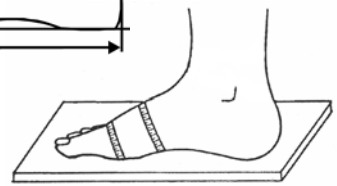
Assist. Prof. Vesna Marija Potočić Matković, Ph.D.

Zagreb, September 05, 2013

The main objective of the Faculty of Textile Technology is to bridge basic science with applied science in order to meet the needs of the textile industry in terms of product design.



Anthropometric studies of the feet based on the Traditional Anthropometry have been published by Prof. Ujević



The aim of this Dissertation is to introduce Geometric Morphometrics in order to achieve a holistic interpretation of shape of the foot

This method can be applied to any part of the body part!

O. Univ.-Prof. Dr.phil. Horst Seidler

Univ. Prof. Darko Ujević, Ph.D.

The research was supported by the Ministry of Science, Education and Sports of the Republic of Croatia (MSES), Grant No. 117-1171879-1887, and the OEAD Bilateral project between Croatia and Austria:

Anthropometry under special consideration of life and early factors with an applied approach for the garment industry

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GEOMETRIC MORPHOMETRICS

Important in the textile technology

Designers could get a very powerful tool in designing

Contributes to a better feet protection for athletes, firefighters, soldiers, workers who stand long during the work

Geometric Morphometrics can contribute to science in the study of the impact of modern lifestyle and contemporary garments and footwear to physical deformities, especially to the human foot

Proceedings of the IEA 2000/HFES 2000 Congress

Statistics for 3D Human Body Forms

Masaaki Mochimaru and Makiko Kouchi
National Institute of Bioscience and Human-technology
Tsukuba, Japan

developed a method for analysing 3D body forms and utilized the form information to product design, based on the FFD

Int. J. Human Factors Modelling and Simulation, Vol. 3, No. 2,

3D anthropometric data processing

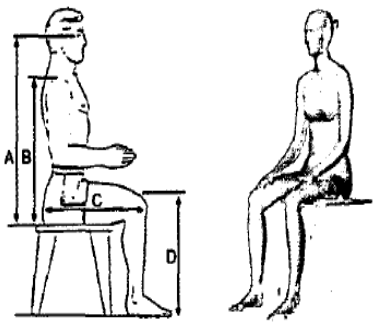
Chang Shu*

concluded that statistical shape analysis reveals patterns of changes in the human shape

PROCEEDINGS of the HUMAN FACTORS AND ERGONOMICS SOCIETY 47th ANNUAL MEETING—2003

A COMPARISON OF THE ROLES OF UNIVARIATE AND THREE-DIMENSIONAL ANTHROPOMETRIC DATA IN THE DESCRIPTION OF FORM

Melinda M. Cerney



suggested that three-dimensional landmarks provide a more complete archival of form than do univariate descriptions

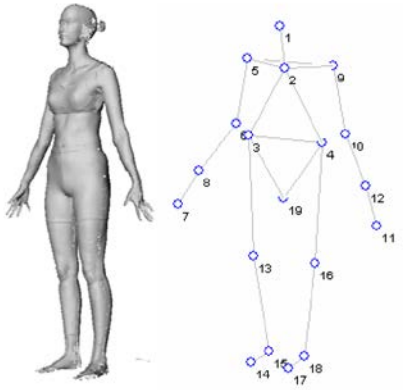
2004. SAE Transactions Journal of Aerospace. 113:208-214.

04DHM-38

Sequestering Size: The Role of Allometry and Gender in Digital Human Modeling

Melinda M. Cerney
Virtual Reality Applications Center & Adams Morphometrics Lab,
Program in Human Computer Interaction, Iowa State University

Dean C. Adams
Department of Ecology, Evolution, and Organismal Biology,
and Department of Statistics, Iowa State University



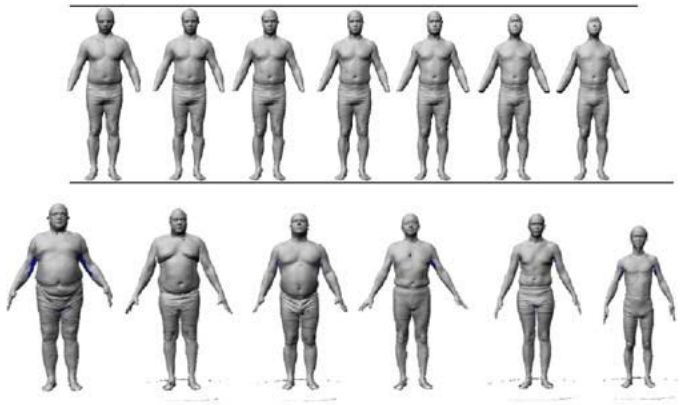
suggest that body shape represents an equally important component of variation in human form and therefore must be taken into account during design procedures

Visual Comput (2006) 22: 302–314
DOI 10.1007/s00371-006-0006-6

ORIGINAL ARTICLE

Zouhour Ben Azouz
Marc Rioux
Chang Shu

Characterizing human shape variation using 3D anthropometric data



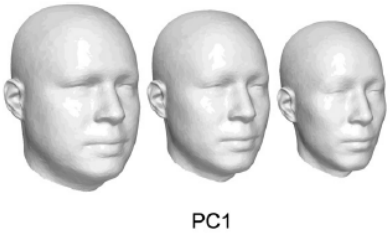
pointed out characterizing the variations of the human body shape is fundamentally important in many applications from animation to product design

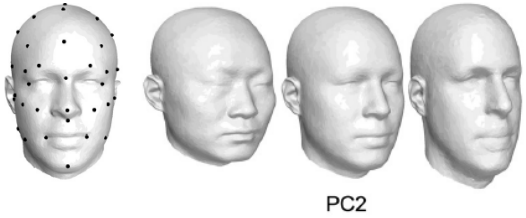
Applied Ergonomics 41 (2010) 832–839

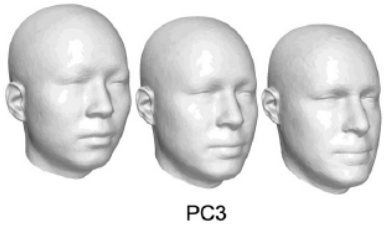
Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo







A comparison between Chinese and Caucasian head shapes☆

Roger Ball [a,*], Chang Shu [b], Pengcheng Xi [b], Marc Rioux [b], Yan Luximon [a], Johan Molenbroek

[a] The Hong Kong Polytechnic University, School of Design, Core A, Hung Hom, Kowloon, Hong Kong
[b] National Research Council of Canada, Canada
[c] Delft University of Technology, The Netherlands

The 3D Chinese head and face modeling

Yan Luximon *, Roger Ball, Lorraine Justice

School of Design, The Hong Kong Polytechnic University, Hong Kong

2012

(a) Male model. (b) Female model.

Fig. 10. The average 3D Chinese head and face model.

Computers & Graphics 36 (2012) 410–416

Contents lists available at SciVerse ScienceDirect

Computers & Graphics

journal homepage: www.elsevier.com/locate/cag

SMI 2012: Full Paper

Posture-invariant statistical shape analysis using Laplace operator ☆

Stefanie Wuhrer [b,c,*], Chang Shu [a], Pengcheng Xi [a]

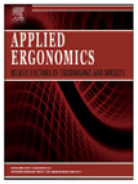
[a] National Research Council of Canada, Canada
[b] Saarland University, Germany
[c] Max Plank Institute Informatik, Germany

Applied Ergonomics 44 (2013) 775–784

Contents lists available at SciVerse ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo



Head-and-face shape variations of U.S. civilian workers

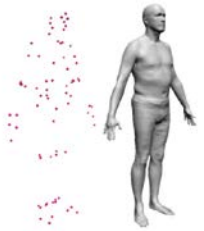
Ziqing Zhuang [a,*], Chang Shu [b], Pengcheng Xi [b], Michael Bergman [a], Michael Joseph [a]

[a] National Institute for Occupational Safety and Health, National Personal Protective Technology Laboratory, Bruceton Research Facility, P.O. Box 18070, 626 Cochrans Mill Road, Pittsburgh, PA 15236, USA
[b] National Research Council of Canada, Institute for Information Technology, Ottawa, ON, Canada K1A 0R6

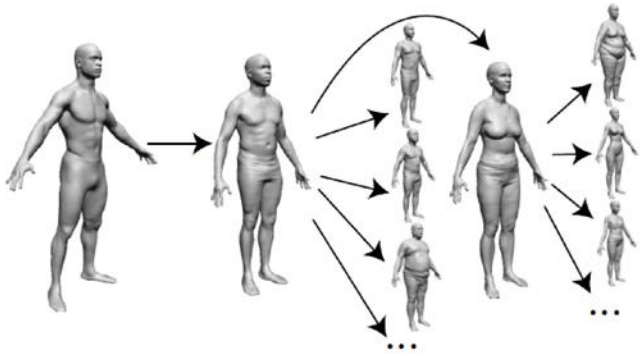
"It is expected that new designs could benefit from the results that are guided based on 3D information"

STATISTICAL ANALYSIS OF HUMAN BODY SHAPES

Allows quantification of shape variability of a population



Helps to understand certain body shapes

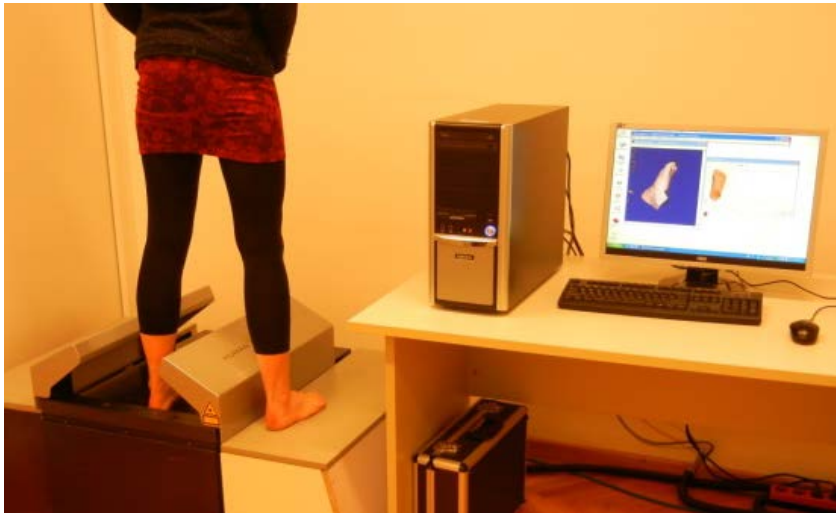


Gives a detailed visualization

Describes the human body in higher degree than Traditional Anthropometric methods

New technology

3D foot scanner Pedus
Record 3D shape database



Statistical Shape Analysis

A new approach to anthropometric measurement based on 3D scanning technology

Shape Space Representation

Information about the human foot variation

HYPOTHESES

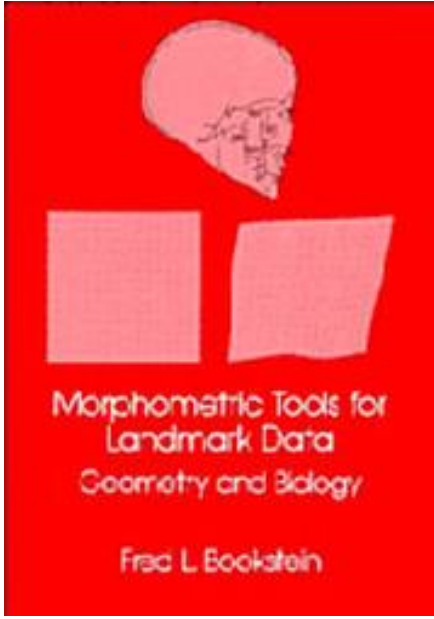
H1 Shape differences correspond to geographical origin
rejected, respectively needs further research work

H2 Foot morphology differ in shape and asymmetry within and among individuals
confirmed

H3 Foot morphology is influenced by an increase in body weight (BMI)
confirmed

H4 Wearing high heel shoes influences the plantar foot morphology in early age range
confirmed

Fred Bookstein –
father of GM
h-Index over 60
13.000 citations



Geometric Morphometrics refers to the quantitative analysis of **form**, a concept that encompasses **size** and **shape**.
The major objective of morphometrics is to statistically test hypotheses about the factors that affect shape (e.g. high heels!)

Philipp Mitteröcker
evolVienna Faculty and Group Leader
Department of Theoretical Biology, University of Vienna
Subjects: morphometrics, multivariate statistics

…developing geometric morphometric methods and multivariate statistical tools to study phenotypic evolution and development in humans and other primates

TRADITIONAL OR MULTIVARIATE MORPHOMETRICS

Analyzes lengths, widths, masses, angles,
ratios and areas

Linear distances usually highly correlate with size

GEOMETRIC MORPHOMETRICS

Based on Landmark coordinates, measurement of points
This technique was invented in the 1980s as a sort of revolution in morphometrics as a shape theory

Shape is the geometry of an object and is invariant under the change of position, orientation and scale.

Size is any positive, real-valued measure of an object that scales as a positive power of the geometric scale of the form

Form reffers to the geometry properties that are invariant to changes of translation, orientation but not in scale

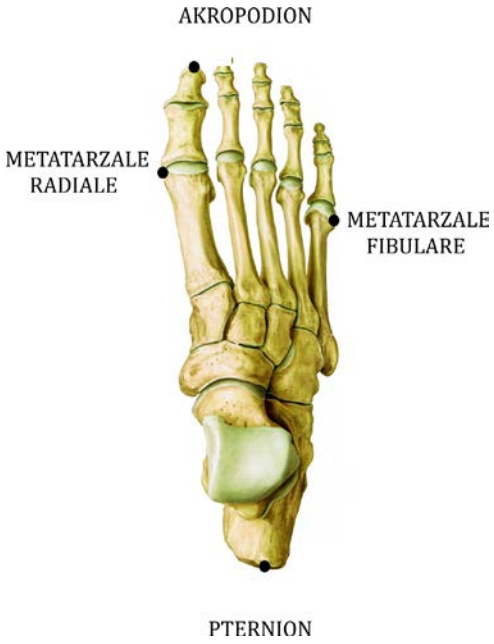
Form = Shape + Size

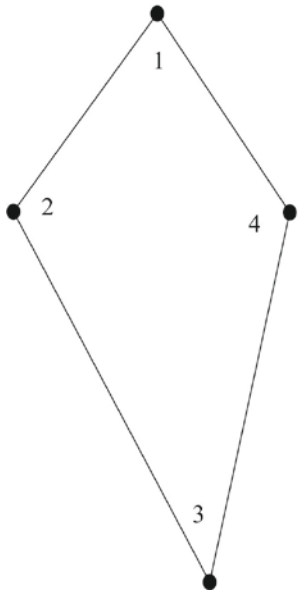
PROCRUSTES SUPERIMPOSITION

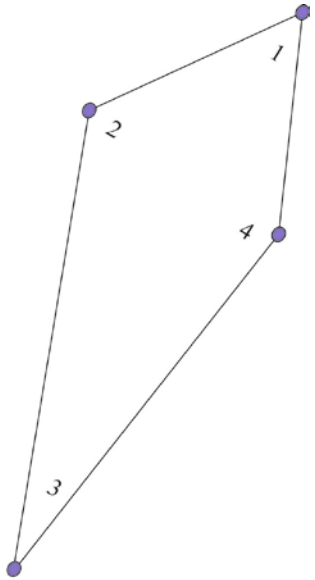
In the Greek myth, Procrustes was a son of Poseidon

Morphometrics is aimed to separate shape information from nuisance parameters

PROCRUSTES SUPERIMPOSITION

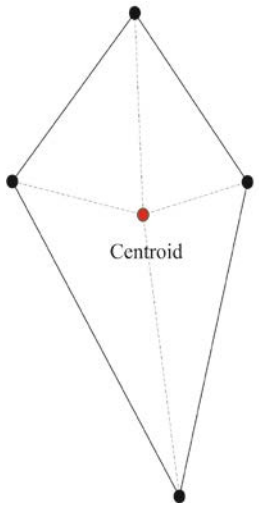




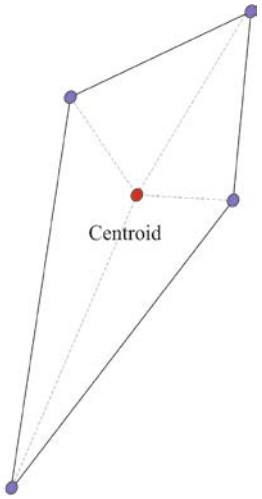


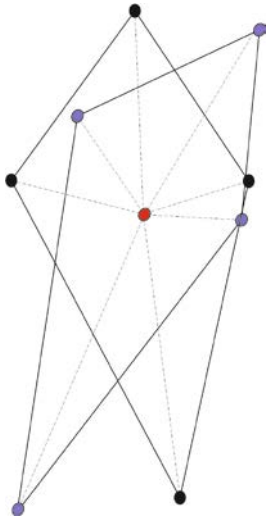
4 anatomical landmarks
on the plantar side of the foot

PROCRUSTES SUPERIMPOSITION

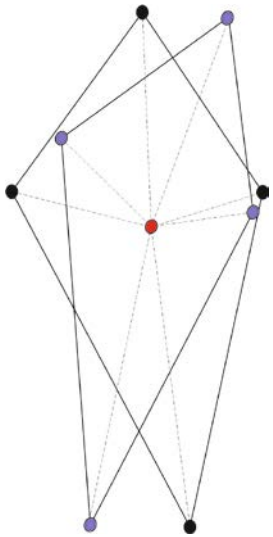


Compute centroid of each configuration

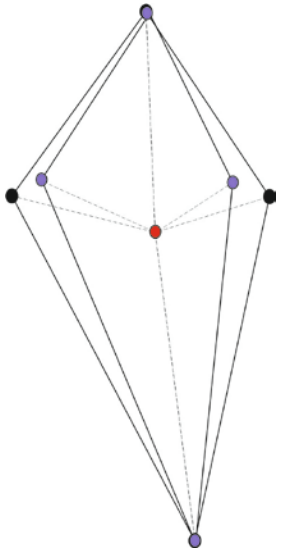




Centered landmarks



Centered and scaled landmarks



Centered, scaled and rotated landmarks

PROCRUSTES SHAPE COORDINATES

Landmark coordinates after the Procrustes superimposition represent the shape of an object

If two configurations have the same shape they should be identical!

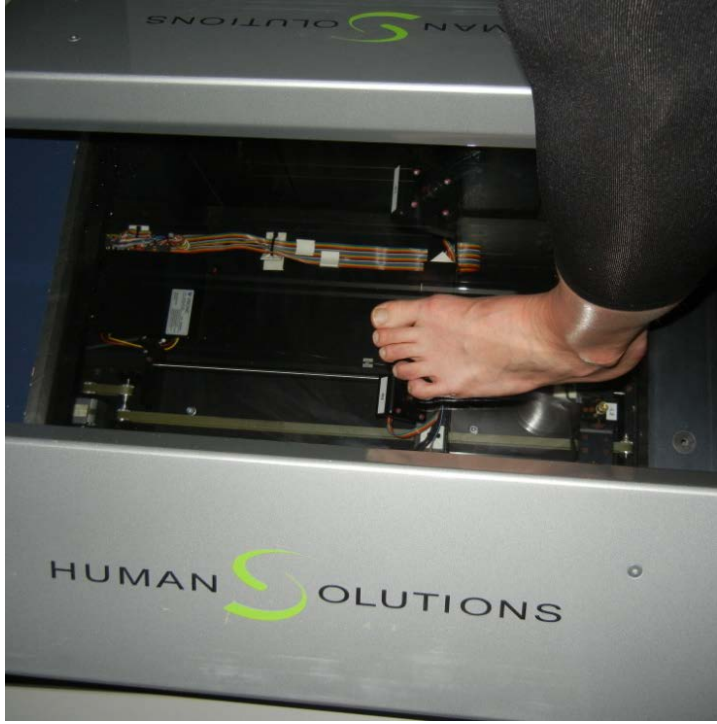
The shape variables all possess the same units

N= 83 female individuals, aged between 19 and 36 years

Three-dimensional Surface Foot Scanner *Pedus*

A questionnaire was used to recorded:
shoe wearing habits
frequency of wearing high heels

BMI was calculated using the Quetelet Index, body mass divided by height squared



$$PI = \frac{weight\ (kg)}{height^3\ (m^3)}$$

$$BMI = \frac{weight\ (kg)}{height^2\ (m^2)}$$

DATA AQUISITION

3D Data Shape

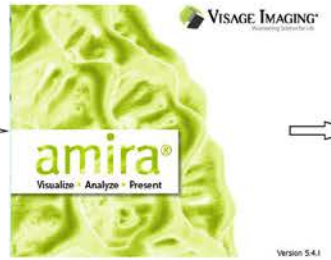
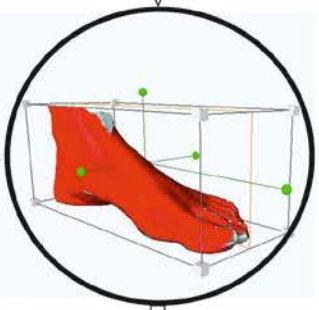


IMAGE PROCESSING



3D EXPLORATION

SEGMENTATION

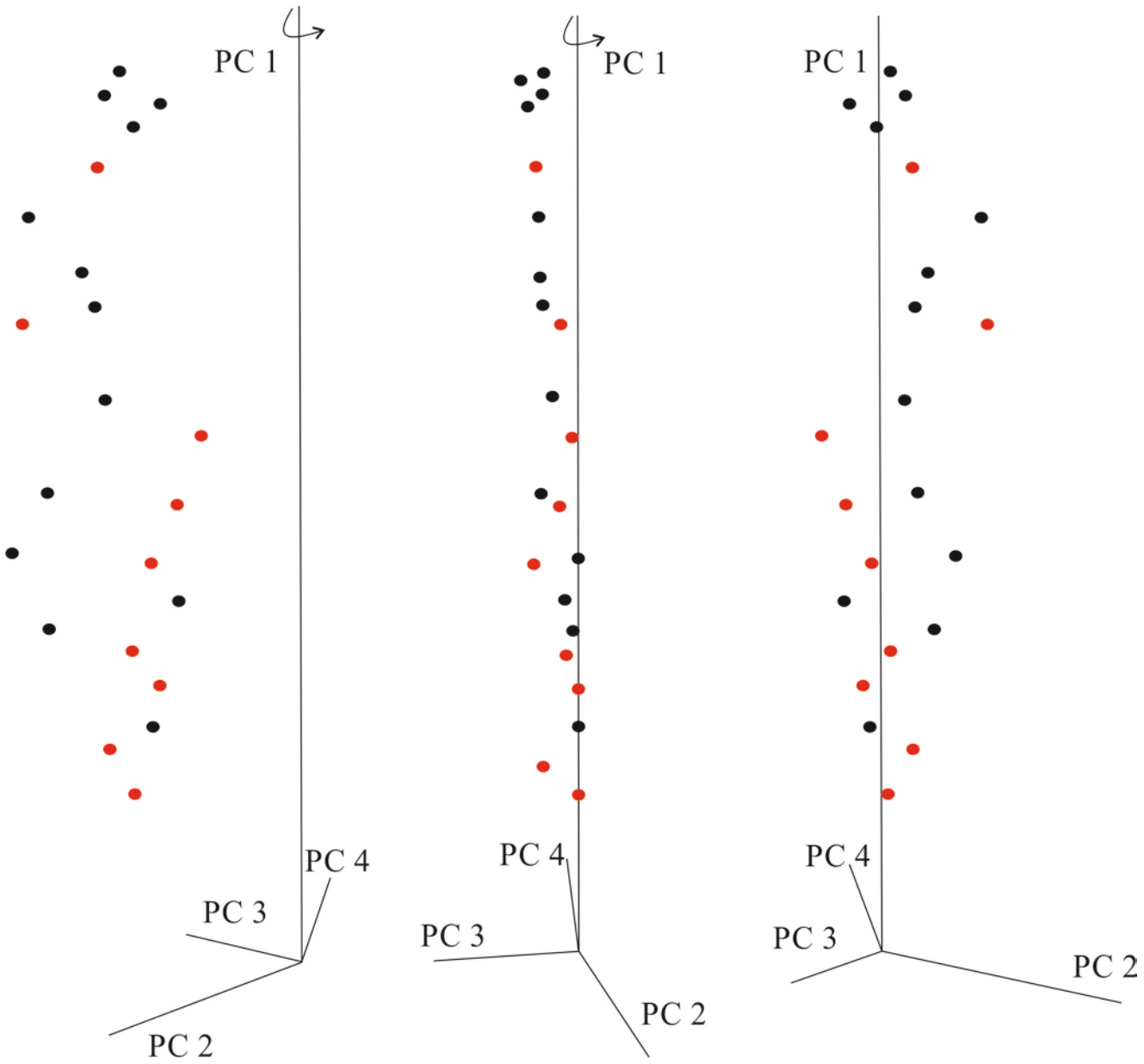
SAMPLE SIZE

332 Female feet

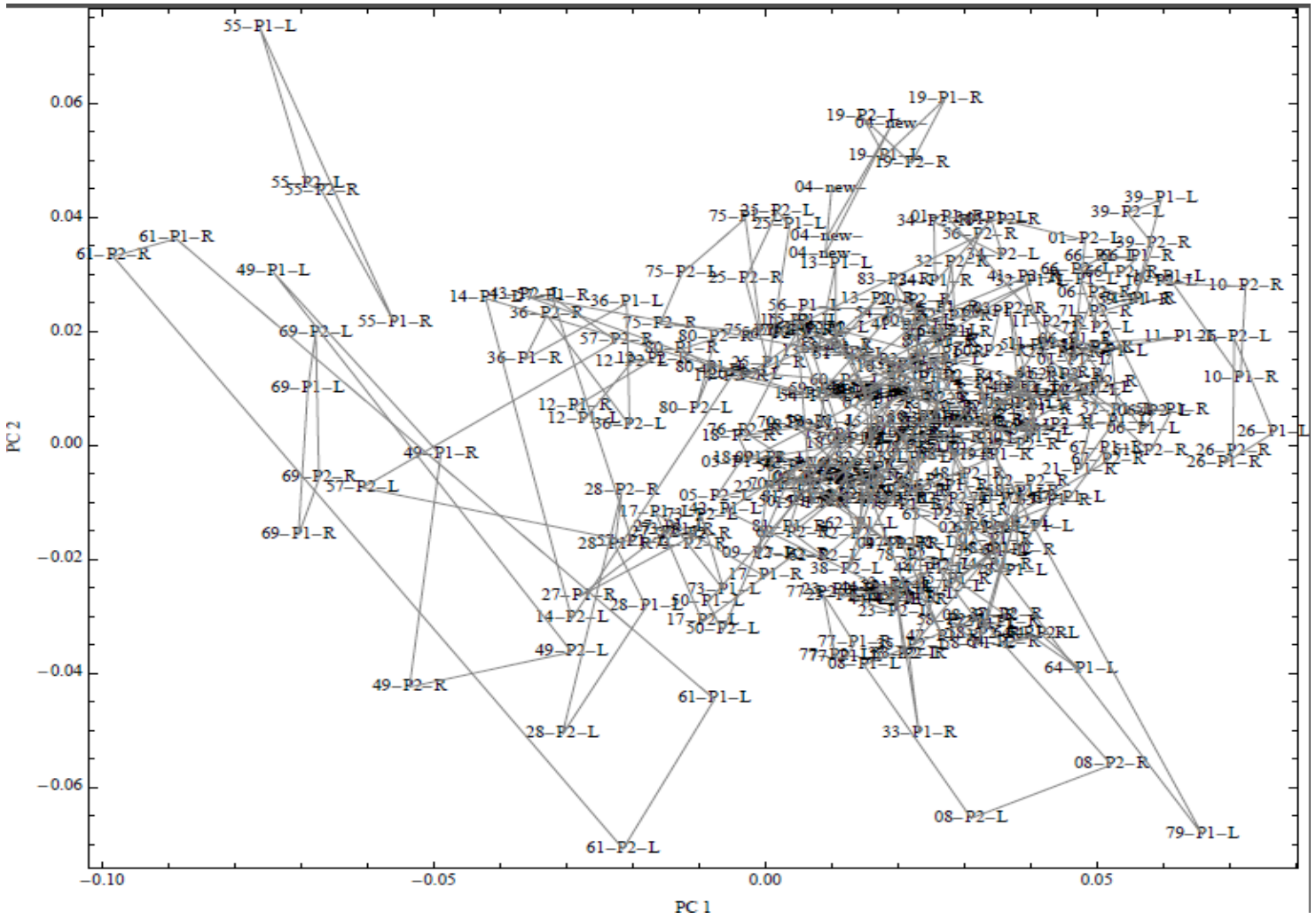
28 220 Landmarks

56 440 Variables

Principal Components Analysis

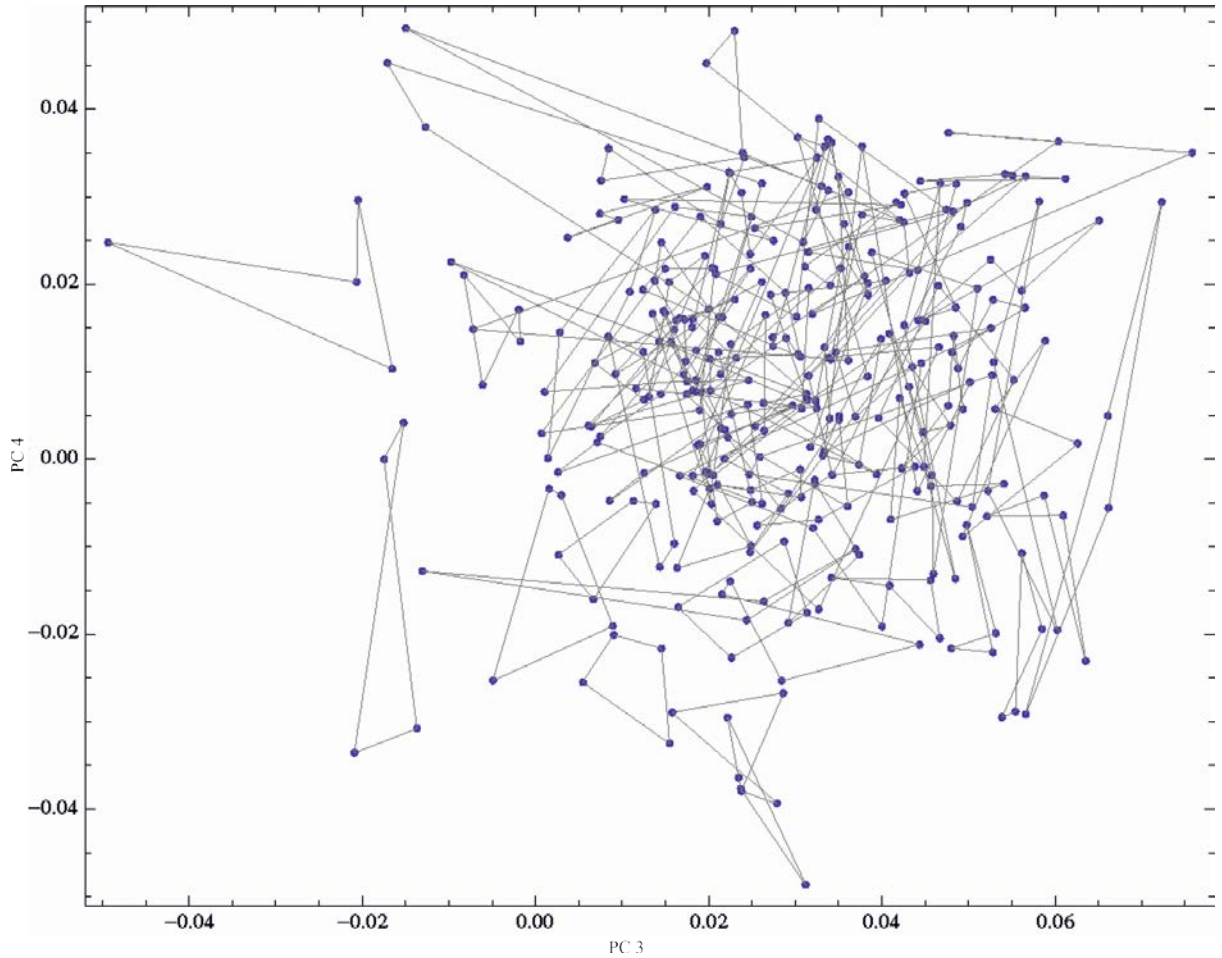


PC	Eigenvalue	Expl. Variance	Cum. Expl. Var.
1	8.21×10^{-4}	21.28%	21.28%
2	5.24×10^{-4}	13.57%	34.85%



Every symbol in the scatterplot represents the footprint shape of one person, a total of four scans were made for each person, two of the left foot and two of the right foot and connected with a line

3	3.41×10^{-4}	8.82%	43.67%
4	3.20×10^{-4}	8.29%	51.97%



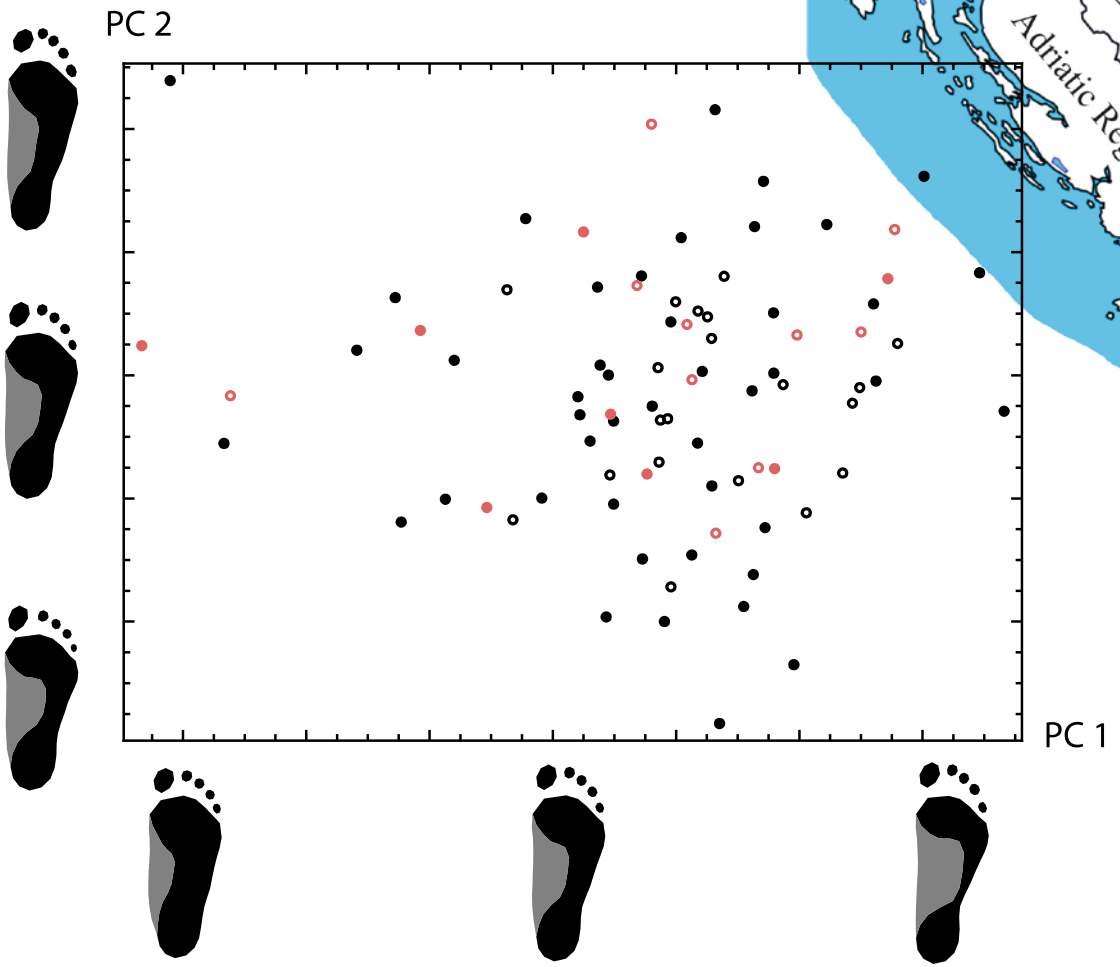
Every symbol in the scatterplot represents the footprint shape of one person, a total of four scans were made for each person, two of the left foot and two of the right foot and connected with a line

H1 Shape differences correspond to geographical origin

rejected, respectively needs further research work

Long and narrow feet with long toes

Short and wide feet with short toes



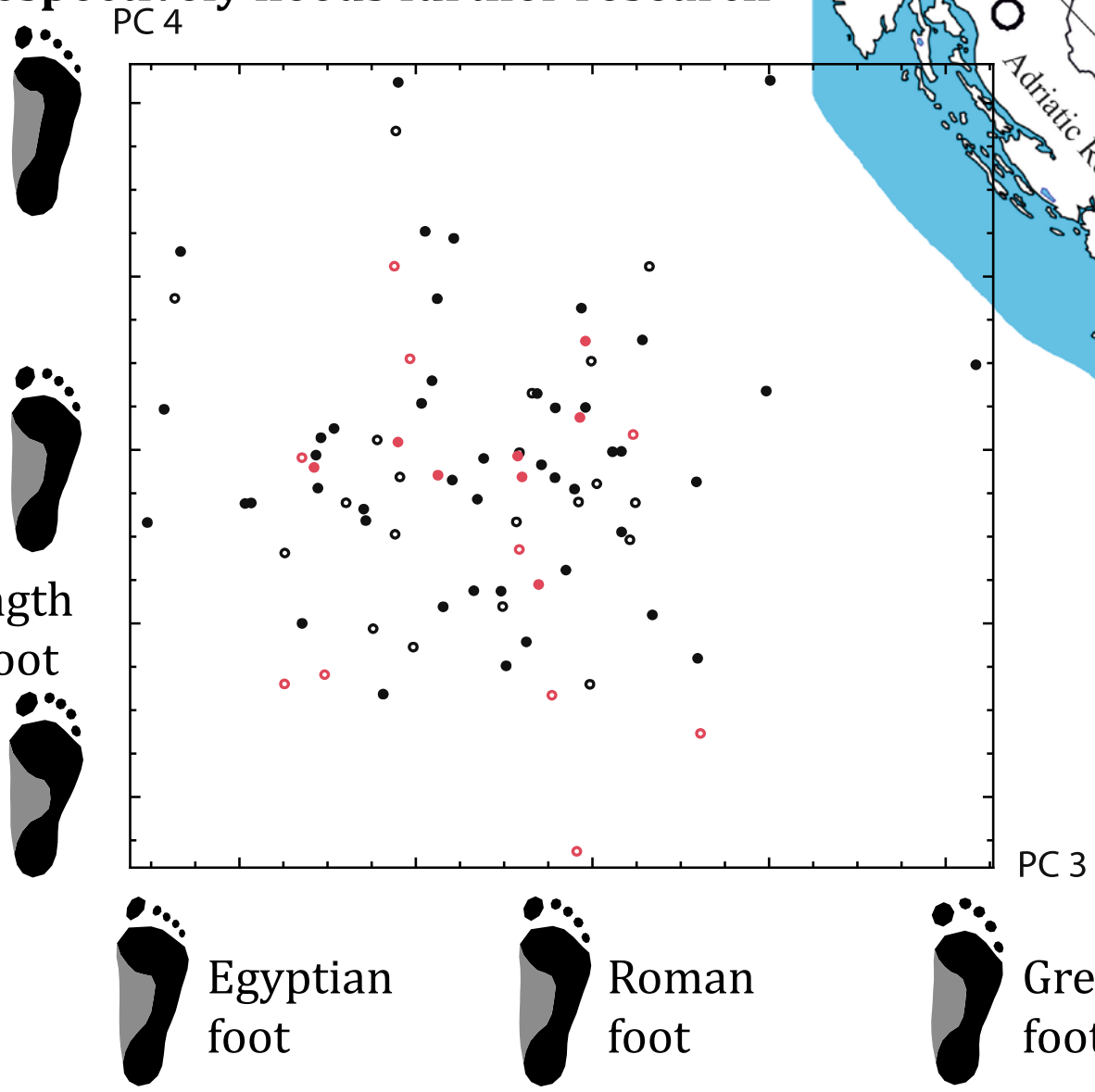
Flatfeet
Pes planus

Pes rectus

High-arched feet
Pes cavus

H1 Shape differences correspond to geographical origin

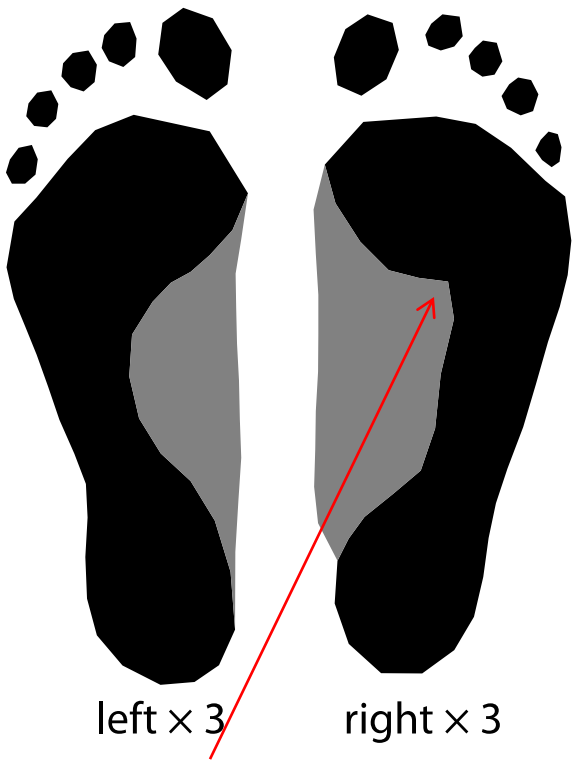
rejected, respectively needs further research work



FOOT ASYMMETRY

H2 Foot morphology differ in shape and asymmetry within and among individuals **confirmed**

Left and right footprint differ significantly at $p < 0{,}001$



Right footprints on average have a slightly increased width relative to the length

The border between the forefoot and the midfoot is more angulated in right feet than in left ones

BODY MASS INDEX

H3 Foot morphology is influenced by an increase in body weight (BMI) **confirmed**

BMI 15 BMI 30

Body mass index (BMI) had a significant effect on footprint shape ($p < 0{,}001$) and explained 2,8% of total shape variation

A low value of BMI is associated with a more arched foot and a high BMI with a flatter foot

BODY MASS INDEX

HIGH HEELS

H4 Wearing high heel shoes influences the plantar foot morphology in early age range **confirmed**

The frequency of wearing high heels significantly explains 1,8% of total shape variation (p = 0,003)

People who often wear high heels tend to have a relatively longer forefoot and a more anterior positioned hallux relative to the other toes

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JOURNAL OF FOOT AND ANKLE RESEARCH

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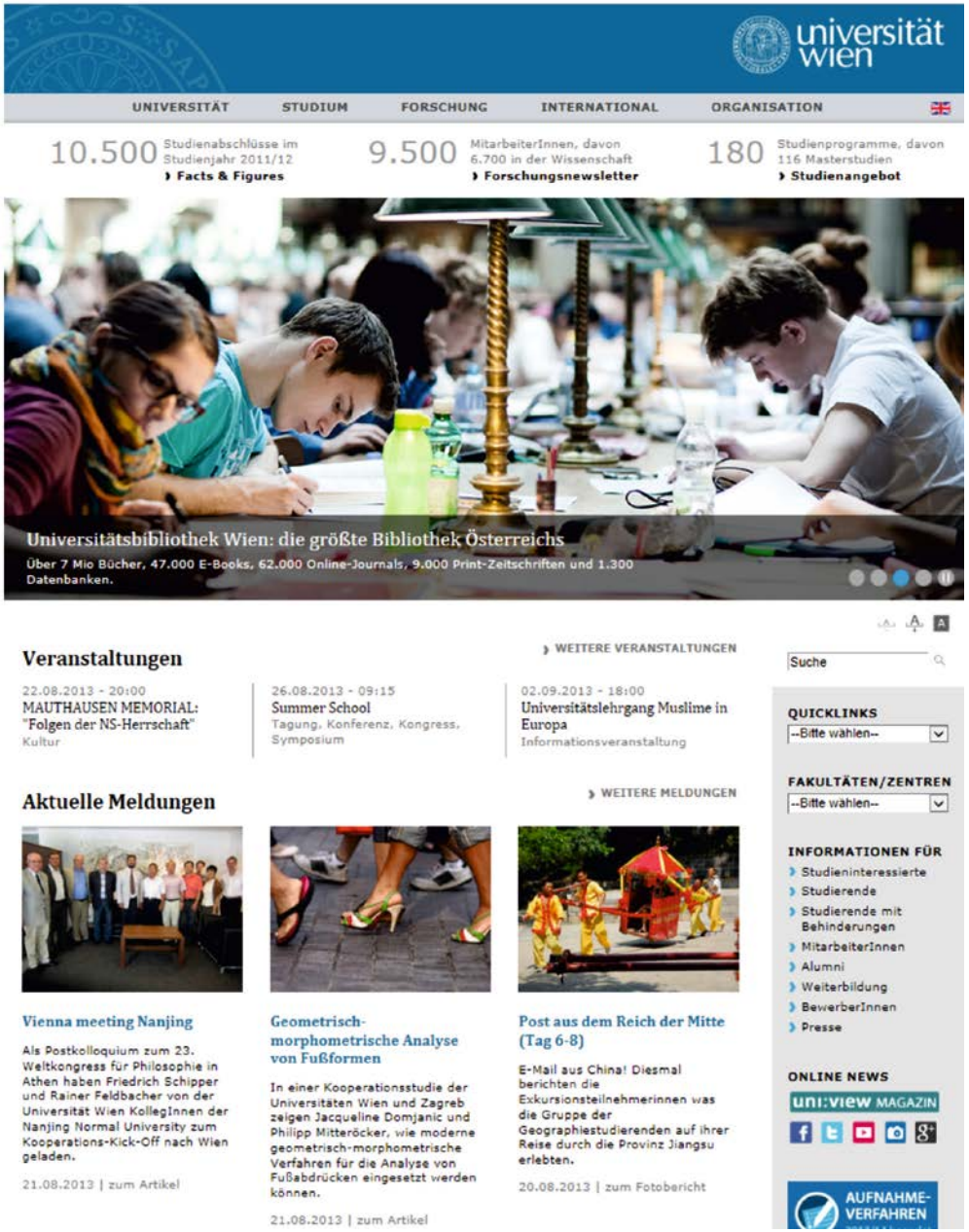
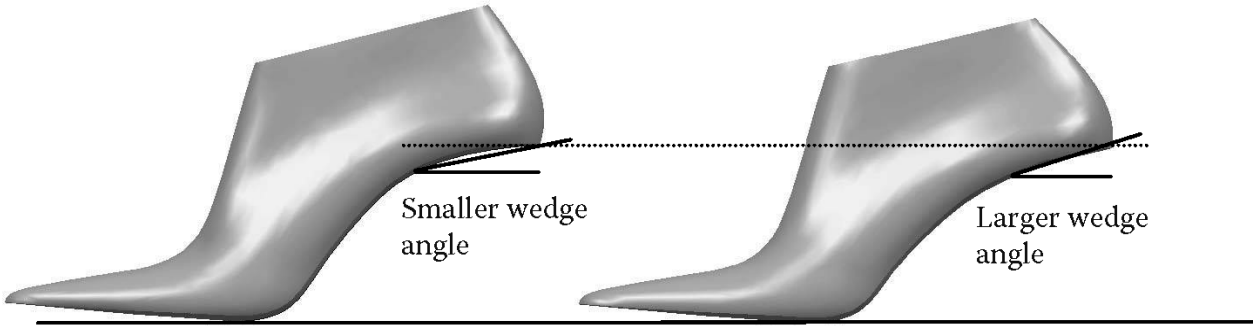
Domjanic *et al. Journal of Foot and Ankle Research* 2013, **6**:27
http://www.jfootankleres.com/content/6/1/27

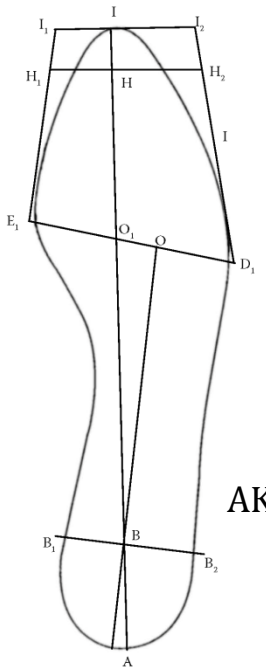
JOURNAL OF FOOT AND ANKLE RESEARCH

METHODOLOGY Open Access

Geometric morphometric footprint analysis of young women





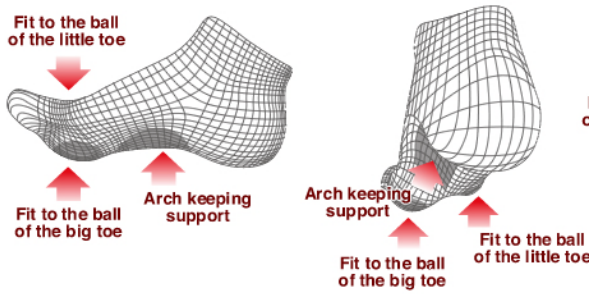


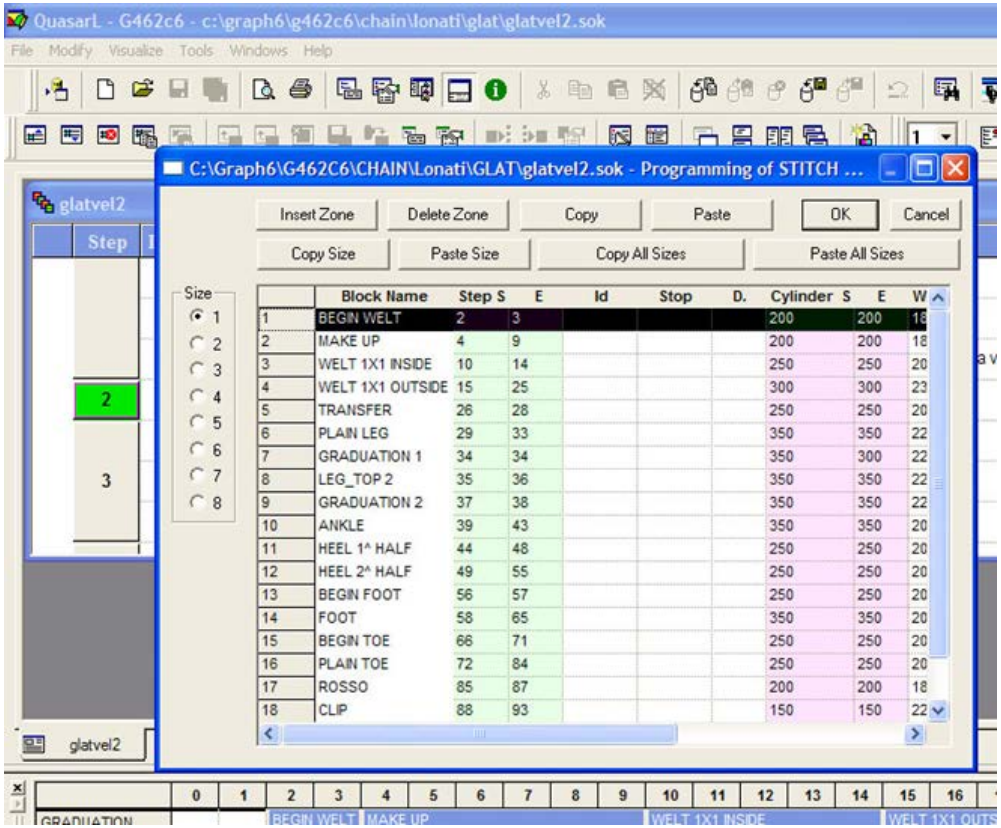
Midsole, insole and outsole represents the surface on which the shoe is supported

AKA SYSTEM

Sock is the layer of material that sits directly next to the skin and is intended to comfort and protect the feet

The sock / shoe combination must welcome the foot in order to function properly, thus to choose socks of the correct size and that fit the feet properly is very important





Conclusions

Geometric morphometrics was used to study patterns of morphological variation of female feet

Several directions of variation were observed in the overall sample analyzed in this study

Geometric morphometrics prooved to be a powerful tool for the detailed analysis of footprint shape that is applicable in various scientific disciplines, including orthopedics, and footwear design

This visualization allows effective exploratory studies and discovery of new and possibly unexpected patterns in the data

Geometric Morphometrics can contribute to science in the study of the impact of modern lifestyle and contemporary garments and footwear to physical deformities, especially to the human foot

FUTURE COLABORATIONS

Faculty of Life Science
O.Univ.-prof. Dr. phil. Horst Seidler
Univ. Prof. Dr. Fred L. Bookstein, Ph.D
Univ. Doz. Dr. Philipp Mitteroecker
Institute for Anthropological research
Univ. Doz. Dr. Saša Missoni
Univ. Doz . Dr. Ivor Janković
Prof. Dr. Zvonko Orehovec , colonel (r)
National Protection and Rescue Directorate
Ministry of Defence
Croatian Defense Industry Cluster
Faculty of Kinesiology
Assoc. Prof. Dennis Slice (Florida State University)
Brian Corner, colonel from the (U.S. Army Soldier Research)

Collaboration in order to analyse and define the human body morphology using GM for special users such as military, police, firefighters but also knowledge that is needed in certain sport activities.

Acknowledgement

Univ. Prof. Darko Ujević, Ph.D.
O.Univ.-Prof. Dr. phil. Horst Seidler
Univ. Prof. Dr. Fred L. Bookstein, Ph.D.
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"When our feet hurt,
we hurt all over"
Socrates

Thank you for your attention!