

FUTURE FOOTWEAR THE BIRTH OF FEET THE RE-BIRTH OF FOOTWEAR

Catherine Willems

Thesis submitted for the degree of Doctor in the Arts: Visual Arts.

June 2015

Academic Year 2014-2015

Research financed by the Research Fund of the University College Ghent.



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THE BIRTH OF FEET

Catherine Willems

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Images of Indian and Finnish feet © Kristiaan D'Août



ACKNOWLEDGEMENTS

This research was financed by the Research Fund of the University College Ghent. I wish to thank my supervisors, Prof Dr Dirk De Clercq, Dr Dirk van Gogh, Prof Dr Gaëtane Stassijns and Dr Kristiaan D’Août, and my former supervisors Prof em. Dr Rik Pinxten and Prof Dr Wilfried Van Damme for their support, guidance, and mentoring over the years. To Kris, a special thank you for being a generous supervisor who introduced me to the scientific world of feet. To Rik for his open mind and positive advice over the last 15 years and for stimulating me to start this project. I am also grateful for the support I received from Prof Dr Wim Cornelis for the soil analysis and from Prof Dr Carla Hertleer for the material analysis. Thanks also go to Prof Dr Tim Ingold for the inspiration offered through his writings and during my research stay at the University of Aberdeen in 2012.

The practical elaboration of the project would have been impossible without the intensive collaboration of Vivobarefoot, UK, with a special thanks to Galahad for his thinking ahead, to Asher for his design sharing, to Joël for being helpful on different levels, to Lee, to Lucy, and to the full Vivobarefoot team.

For the 3D printing with STL I want to thank Jempi Wilssens and the team at RSPrint for the promising collaboration. I want to thank René Medel, industrial designer at SLEM, for his work on the 3D files. His work and hours are greatly appreciated.

For the excellent and extremely fast work on the graphic design, I thank Marcel Lennartz.

The beautiful photography in this volume is the work of David Willems and Kristiaan D’Août.

My sincere gratitude goes to the artisans and the management of Toehold Artisans Cooperative and of Dastkar, for their enthusiastic participation and extensive support throughout this project. Bagwan Das, Prahalaad, Anil and Maruthi and Mahadevi, it was a joy to work with you! A special thanks to Ms. Madhura Chatrapathy and Mr. Raghu of Toehold, Ms. Ujwala of Dastkar and Ms. Devika Krishnan for facilitating all logistics and communications between me and the artisan communities. Thank you Ujwala and Devika for the nice evenings next to the fire. My deep gratitude goes to Mr. B.N. Das of CLRI for his support and the technical expertise he shared with me. My utmost gratitude goes to the people in Inari and to Soggsak, for the facilities offered at the Saami Education Center. Warm thanks go to Virpi, Kikka and Satu for the countless mails and questions and the lovely talks. And thanks to all the artisans and volunteers involved in this project.

Thank you, also, to Wim De Temmerman, Dean of the School of Arts, Ghent, for the opportunity to combine teaching and study, to my colleagues at the Fashion Department, Marina Yee, Liesbeth Louwyck, Eva Bos, Filip Eyckmans, Helena De Smet, Ellen Monstrey, Bram Jespers, Tom Tosseyn, Paul Demets, Hugo De Block, An van Dienderen, Hilde d’Hayere and many others. Thanks to all my students and in particular to Clio Gydé, Marjolein Peter and Ida Jacobs. And thank you Flora and Sofie for being enthousiastic collaborators in the San project. To Kristel Peters and Herman Stroobants, my colleagues in shoe design, a special thanks for help and understanding during the last phase of this research. Thanks to Katrien Vuylsteke for the research follow-up.

In the private sphere, I wish to thank my husband Philippe, for being instrumental in the last stages of writing up this dissertation and for his cooking and managing the household. Lots of love and thanks to my two teenage daughters, Helena and Marta, and all their friends bringing an enormous amount of life and laughter in our house. A special thanks to my parents for being great supporters, with never ending enthousiasm. Thanks for joining me on the first fieldwork to India, and for home educating my children, while I was out in the field. They often brought and picked me up from my several travels and next to them as well to Dany, my mother in law. Together they kept our house warm and full of lovely smells while I was abroad. Thanks to my close friends; Lieven, David, Chris, Sun, Nancy, Gina, Nico, Jeroen, Lieve, Ravi, Mieke, Lisette, Guy, Cathérine, Marcel, Ronald, -and also to those I forgot to mention- for understanding my absence in the last months and for offering many relaxing evenings with bubbles and joy. To every one of you: dank u, thank you, bahut dhanyvad, kiitos.





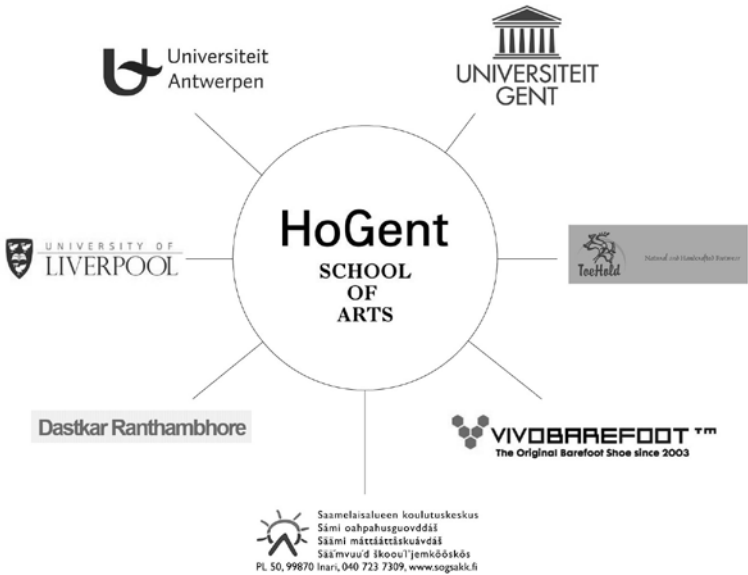




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INTRODUCTION

Anthropology, design and biomechanics: perspectives on feet and footwear



Introduction

Six years ago I started with ‘Future Footwear’ a PhD in the arts at KASK, School of Arts, University College Ghent. From the outset I wanted to combine footwear design and anthropology. I also wanted to explore the impact of footwear both on the environment and on body and gait, and for the latter I needed expertise in biomechanics. The resulting academic and artistic PhD project on shoe design thus integrates across three disciplines – design, anthropology, and biomechanics – and analyses adequate cases for comparative research and innovative design.

In this general introduction I first reflect on the historical and ecological context of the use and the making of footwear. I then describe the set up of the ‘Future Footwear’ project, including methodology, and give a brief summary of the structure of the thesis, including the scope of and the relationships between the different chapters.

The context of ‘Future Footwear’: historical and ecological reflections on footwear and gait.

Looking at contemporary footwear, one might think that there is a trade-off between form and function, whereby elegant footwear is not comfortable, and vice versa. From simple foot coverings to high heeled shoes, footwear reflects different cultures, fashions, and behaviours and does not always serve a practical purpose. Footwear appears to have two main sets of requirement, which reflect different types of function. The first function is cultural, by which I mean all aspects of the shoe that are predominantly linked to form and are determined by learned skills, social relations, aesthetics, and meaning in a specific context. The second function is biomechanical, by which I mean all aspects that are predominantly linked to use and which should allow a shoe to be used as a “practical tool” for walking in an injury-free, comfortable way –including providing isolation in cold climates– irrespective of “looks”. In reality, these two functions are rarely completely separate, although it is easy to see how, for instance, stilettos and walking boots are situated at opposing ends of the spectrum (Willems and D’Août, 2013).

Let us first look at two examples of footwear that have a predominantly cultural purpose.

The first example dates back more or less a millennium and is found in footbinding, also known as Chinese lotus shoes. Lotus shoes were first worn by upper-class women in China, but at the beginning of the 17th century they were adopted by women of all classes in order to imitate the elite. The practice of foot binding was not a uniform, and both the technique of binding and its meaning changed with time and place (Ko, 2001). In general, small feet were considered beautiful and attractive, and the ideal length of the shoe was no more than 6 cm. The shoes are cone shaped –intended to resemble a lotus bud– and are made of decorated cotton and silk. From the age of six years on, the toes of girls were broken (with the exception of the big toe) and bound daily, or every couple of days, with cloth to reshape the feet and prevent further growth. Several studies have shown that habitual use of footwear from early childhood can influence the shape and function of the foot, but traditional Chinese foot binding is an extreme example showing that the human foot is a highly plastic structure. Although this type of footwear meant that the girls had to suffer, it also displayed their privileged position and association with a higher class. These women were exempt from work and had servants to take care of them. Footbinding was common until the 1950s, when it was prohibited and abolished under the communist regime.

A second cultural example is the Paduka. Paduka is the name of India’s oldest, most typical footwear, but not the most functional in a biomechanical understanding. In fact, it is little more than a sole with a toe-knob, positioned between the big and the second toe. The Paduka exists in a variety of forms and materials throughout India. It can either be designed in the shape of actual feet or of fish and are made of wood, ivory, and even silver (Jain-Neubauer, 2000). Simple wooden Padukas were worn by common people, but Padukas of fine teak, ebony, and sandalwood, inlaid with ivory or wire, were a mark of a wearer’s high status. Today, these toe-knob sandals are usually associated with the Indian ‘sadhus and sadhvis’, the ascetic holy men and women who wander from village to village. They are worn to protect the feet against hot and dirty surfaces. The two narrow, curved stilts reflect the principle of non-violence practised by Hindu Brahmins, certain other castes, and Jains, to minimise the risk of accidentally trampling insects and vegetation.

The Lotus shoe and the Paduka are two rather extreme examples of deforming and restrictive footwear, and still they can be extended to contemporary shoes, such as designs by Alexander McQueen, Christian Louboutin, or Jimmy Choo. Such shoes are not designed to stimulate natural gait – in some cases quite the opposite – and often lead to hammer toes, bunions, ingrown toenails etc. From simple foot-coverings to high-heeled shoes, footwear does not always serve a practical purpose. As Louboutin once said in an interview: “I have no problem with the idea of comfort but it is not an important thing aesthetically”. Different climate and local environments can lead to different footwear (which in turn might influence the way people walk). Local skills, traditions, and their meaning also find their way into different shoe designs. But one thing people around the world have in common is ‘bipedal locomotion’, that is, upright walking.

Walking is a fundamental part of human experience. People started to walk on two legs about 6 to 7 million years ago, and it took another 4 to 5 million years to have feet as we have them now (Lovejoy, 1988). The modern feet functions differently from those of early ancestors in the sense that we cannot only walk with them but also run. Over time, our toes became shorter and in line with one another (Bramble and Lieberman, 2004). The oldest evidence of our anatomically modern feet belonging to the homo erectus is found in Kenya in the Ileret footprints and date back 1.5 million years (Bennet et al., 2009). These people were able to walk and run, and they did it barefoot. This means that for most of our evolution we have walked barefoot. Humans may have wrapped their feet in skins earlier, but archeologists estimate shoes originate between 40,000 and 26,000 years ago (Trinkaus, 2005). The oldest sandal known—some 10,000 years old—was found in Fort Rock Cave in central Oregon in 1938 (Kuttruff, 1998); it was made out of natural fiber and (presumably) worn by native North Americans. Anatomically, all people presently living on Earth have the same modern feet. But how we wrap them and how we walk differs.

Unfortunately wearing shoes nowadays all too often means wearing ‘restrictive’ shoes, and thus there is a high risk that shoes become an instrument of deformation. Our undeformed (natural) foot’s outline is not symmetrical. The big toe extends from one to two inches beyond the fifth toe. And our five toes spread out fanlike. They do not converge to a point in front as one would expect from the shape of many shoes.

Beside the negative effects of shoes on feet, with the industrial production of footwear also comes the problems of mass consumption regarding the materials used. The footwear industry is a manufacturing sector which utilises a wide variety of materials and processes to produce a range of different

Fieldwork sites (India and Finland) indicated with red dot



X-ray of Lotus feet and female legs wearing a pair of high heels

products, from sandals to more specialised footwear (such as running shoes).

The worldwide per capita consumption of footwear has increased considerably, from 1 pair of shoes per year for every person in the world in 1950 to almost 2.6 pairs of shoes in 2005. Currently, more than 20 billion pairs of shoes are produced worldwide every year. This creates a large waste stream at the end of the functional life of shoes, as they are all too often disposed in landfills, which is environmentally the worst option for waste (Claudio, 2007) Staikos and Rahimifard, 2007):

The project ‘Future Footwear’

Starting from this historical, biomechanical, and ecological reflection on footwear I wondered if indigenous footwear – worn in various regions of the world – would have similar damaging effects on feet and environment. Two general research questions were formulated at the beginning of the PhD:

- 1. How can we design footwear that respects human natural anatomy and offers maximum protection?
- 2. How can we create footwear that does not degrade the source and sink functions of our environment and that, thus, keeps our natural capital intact?

In the context of indigenous footwear, these questions can be phrased as follows:

Does indigenous footwear provide an adequate compromise between cultural and biomechanical needs?
Can the role of the ‘indigenous’ be more than just a form-related inspiration in the design of new footwear? Can it guide sustainable production for feet and environment?

The PhD research is interdisciplinary, with input from design sciences, biomechanics, and anthropology, and explores the use

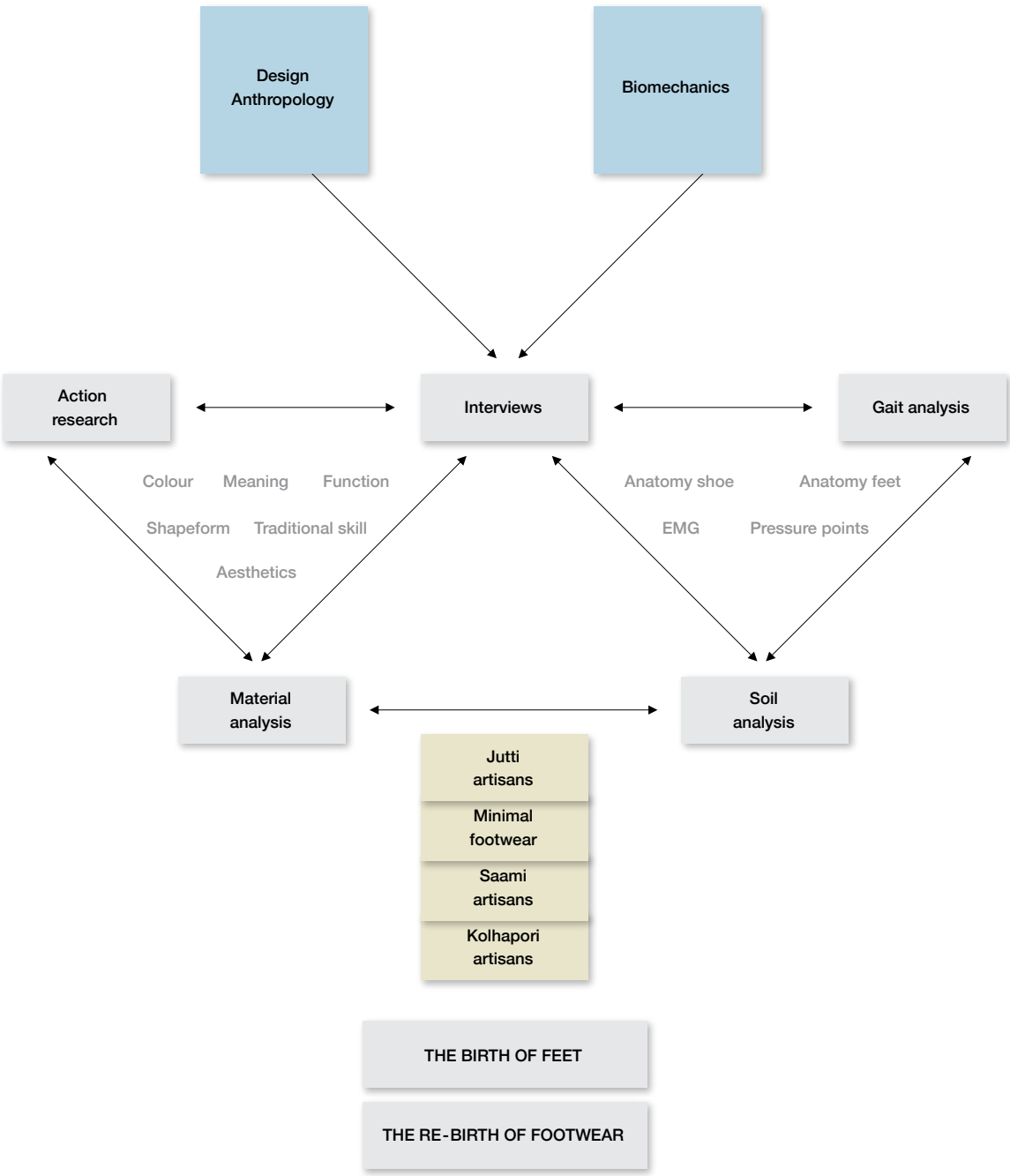
of context related knowledge in design. It explores the relation between materials, skills and creative practices of designing and walking.

I selected three cases of indigenous footwear: South India on Kolhapuri sandals, North India on Jutti footwear, Northern Europe on reindeer fur boots. In addition, a case of contemporary footwear – ‘Vivobarefoot’ (London, United Kingdom)– is considered to enable comparisons of biomechanical performance and traditional and modern ways of producing. The indigenous cases were selected for comparative reasons: winter versus summer footwear. The project started with research of Kolhapuri sandals and reindeer boots –the jutti case was added in 2001 and resulted in a closed footwear line in addition to sandals and boots. Vivobarefoot has been an inspiring collaborator since the fourth project year. I chose to work with Vivobarefoot because the way it combines biomechanical and (sustainable) design aspects in footwear is closely aligned with my own vision.

The above mentioned Paduka might be the best known type of Indian footwear in the Western world, but it is not the most common footwear in India. Even in ancient times, the most common footwear was a strapped sandal of the type that Mahatma Gandhi wore (and made) 2000 years later. Although trends of high-heeled shoes and wedges are followed in India, this flat leather sandal is still widely used and is better known under the name of ‘kolhapuri footwear’. Kolhapuri footwear, made out of vegetable tanned buffalo hides, originates from the districts of Karnataka and Maharashtra and is worn all over India. I worked with the Kolhapuri artisans of Toehold, a not-profit organization in Athni, Karnataka, that promotes the empowerment of rural women with an emphasis on social accountability.

In Rajasthan (northern India) I worked with

Setup of the PhD study



the jutti artisans of Dastkar. Dastkar Ranthambore is a grass roots social enterprise dedicated to providing an alternative source of income to men and women living around the Ranthambore National Park. Although the jutti a shoe with a closed upper attached to a sole, can be made out of silk or cotton, I focused on the locally made leather jutti. The material used is leather from water buffaloes.

The Saami people mainly wear the nuvttohat (in local North Saami language) or nutukkaat (Finnish), that is, fur boots are made from reindeer skin, in the winter when the temperature is below -10 °C. The Saami, living in the northern parts of Sweden, Norway, Finland, and the Kola Peninsula of Russia, are the only indigenous people in the European Union to have their own language, culture, and means of livelihood. In this case the focus is on the use of vegetable tanned reindeer fur legs, needed for the manufacturing of the nuvttohat.

Methodology

Since we aim for multidisciplinary insights into footwear, we used both qualitative and quantitative analyses. To investigate the cultural component of the footwear we have used various design and anthropological methods, from in-depth interviews with the artisans and other members of the community, to fieldwork and action research among the artisans and apprenticeship with the artisans.

For the biomechanical analyses we used quantitative methods to evaluate gait patterns for four conditions: (1) barefoot on a natural substrate, (2) shod on a natural substrate, (3) barefoot on a hard substrate, and (4) shod on a hard substrate. Techniques resembled those of a typical human gait laboratory.

The research project was approved by the relevant ethics committee of the University

of Antwerp. In all field locations, I collected both quantitative and qualitative data, always with the consent of the interviewee(s). The interviews were recorded with a digital voice recorder and transcribed, and the making of the footwear in Rajasthan was filmed. During more informal social moments I took fieldnotes, for instance for the long conversations during long drives in Finland or India.

Central to the methodology of the thesis is that it is multi-sited. Working in different places typifies what Marcus and others have termed multi-sited ethnography, focussing on a world system rather than just a local context (Marcus 1995, 1998). I travelled by train, by plane, by car, by snowmobile, by bus, by bike, and by foot. The first years of the research dragging the footscan plate around for the measurements, as well as cameras and other equipment. On these trips I was often accompanied by at least one of my supervisors or members of the Vivobarefoot team. Fieldwork was carried out during several shorter visits, ranging from one week to three months between 2010 and 2015 –I visited each community three times. This PhD aims at about combining information of the different disciplines and at exploring design as an evolutionary process. During fieldwork, however, I was confronted with ethically difficult situations linked to my double position as designer and anthropological researcher. This double role had both advantages and disadvantages, but it affected how people engaged with me. An advantage was that I became a co-designer being equally linked to the material we worked with, a disadvantage was that I was seen as someone who might “steal” their knowledge. The most invasive methods, such as the quantitative foot measurements, were done at the second or third visit to the com-

munities, at times when sufficient trust had already been established.

Outline ‘FUTURE FOOTWEAR’

‘Future Footwear’ contains two components: a textual Part One ‘THE BIRTH OF FEET’ and a visual Part Two ‘THE RE-BIRTH OF FOOTWEAR’.

The written part ‘THE BIRTH OF FEET’ contains six chapters on anthropology, biomechanics and design. Some have been published before, other articles are under review or will be submitted to international peer reviewed journals. Because each chapter has been published or prepared for stand alone publication some repetition is unavoidable.

Chapter 1 ‘Anthropology: 100% bag tanned’, describes the indigenous Kolhapuri and Jutti footwear –including its material and the making process in specific. The article reflects on the interactivity of the research and its contribution for design anthropology.

In Chapter 2 ‘Biomechanics: Walking on natural and artificial substrates: The effect of indigenous footwear’ the mobility and function of the human foot is examined during shod and unshod walking on two substrates in the South of India. We investigated biomechanical implications of walking with kolhapuri sandals compared to barefoot walking on natural and on an artificial substrate.

Chapter 3 ‘Biomechanics: Plantar pressures in two types of indigenous footwear, minimal shoes, and western shoes, compared to barefoot walking’ assesses plantar pressure distributions (peak pressures and pressure-time integrals) in three populations: South Indians wearing indigenous footwear (kolhapuri), Northern Scandinavians wearing a very different type of indigenous footwear (nuvttohat), and Western Europeans wearing a commercial “minimal shoe” as well as their own daily footwear. Within each

population, data were compared to barefoot walking.

Chapter 4 ‘Design: creativity and the environment’ and ‘An anthropological reflection on form and matter’ consists of two reflections on feet and footwear design published during my PhD trajectory. They offer a deeper understanding of my work as a designer and anthropologist and show that the knowledge gained during my research is shared with a broader public.

Chapter 5 ‘Anthropology: shoe design as cultural heritage. Nuvvohat, perfect for feet!’ looks at what it means for design researchers who are not part of the indigenous Saami community to make and remake boots that are part of the cultural heritage of the Saami. The article explores possible ways of dealing with (in) tangible cultural heritage.

Chapter 6 ‘The unfashionable foot: Sustainable footwear for environment and body’ is a concluding article dealing with design, anthropology and biomechanics. It analyses the embodied skill of making footwear in the respective communities and the contribution this offers to the design of contemporary footwear that is sustainable for body and gait and for the environment. Based on the features of the indigenous cases this chapter describes the re-creation of a sandal and a winter boot in different production settings from handmade, to semi-handmade, and to 3D printed footwear. The physical tests done on the material are grouped in ‘Annex’, at the end of the chapter.

We end with a brief conclusion, which provides a general overview of the PhD and discusses the main findings as well as directions for future research.

The visual part ‘THE RE-BIRTH OF FOOT-WEAR’ contains a grid with four horizontal lines, representing four indigenous footwear models serving as the overall inspiration and four vertical lines representing the different ways of producing the footwear. The design-related aspects were elaborated in close collaboration with the artisans of both communities and with Vivobarefoot, whose founders joined us on field trips to Athani (January 2015) to make Kolhapuri inspired footwear and to Inari (February 2015) to make nutukkaat inspired boots. In addition I visited the different companies Vivobarefoot works with in Portugal and China. Through this collaboration, we aim at re-creating footwear in four different production units, at sites chosen because of the scale of production and the specificity of tools, techniques, and materials used.

A. Kolhapuri footwear – Athni (India- Karnataka): a chappal with strap over feet and a toering.

B: Bantu footwear – Athni (India-Karnataka)

C: Jutti shoes – Sawai Madhopur (India- Rajasthan)

D: Nutukkaat boot – Inari (Finland – Saami): a winter boot featuring a tongue and a lace to keep the snow out.

1. The X-Indigenous project re-creates footwear with the artisans of the indigenous communities with local materials and techniques both for their own market and abroad.
2. The Hybrid project re-creates the indigenous footwear in two small-scale factories near Porto, Portugal. The production is semi-industrial but still hand cut.
3. The 3D knitted Project in China refers to the latest evolution of woven footwear.

4. The 3D-Print project re-creates the indigenous footwear with 3D printing using low cost printers and selective laser sintering.

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ANTHROPOLOGY



ANTHROPOLOGY

100% bag tanned:
action research generating new insights
on design processes

Catherine Willems

In *Critical Arts*, Special issue 1
Revisiting the ethnographic turn in
contemporary art, Volume 27,
number 5, October 2013, 474-489.

Abstract

This article discusses two examples of experimentation with design and anthropology using action research as a method, combining observations and engagement through making. The author describes the use of action research vis-à-vis handmade footwear in two communities in India, to better understand the design process in its context. The author worked with the Kolhapuri artisans in Athani, Karnataka, and with the Jutti artisans in Ranthambore, Rajasthan, to gather information on the skills of creating footwear and on what it means to make footwear in those communities. In the first part of this article, a description of what is understood by ‘design and making’ is offered. Both cases show that form is not imposed on the material, but that they mutually influence each other. In the second part, the process of action research in the two communities is described. The third part reflects on the interactivity of the research and its contribution for design anthropology. Can we talk about reciprocal ethnography? In the present approach, the apprenticeship the researcher did with the artisans assumes a dialogue and interactivity which results in shared ethnographic power. By focusing on the processes of design formation in a specific environment, the risk of pseudo-ethnography (Foster 1995) –whereby only partial engagement with the community is achieved– is avoided.

Keywords:
action research
anthropology
comparative design practice
culture
footwear
knowledge
skills

Introduction

Footwear reveals much about the world we live in, and about ourselves. Not only does it offer us information about the environment in which we walk and the adapted gait patterns, it also reveals the skills developed in the environment, which is necessary to create the footwear. This article discusses two examples of experimentation with design and anthropology. The making process of two types of handmade Indian footwear is described to better understand the design process in its context. Action research is used as a method of anthropology, combining observations and engagement through making. Having worked with the Kolhapuri artisans in Athani, Karnataka, and with the Jutti artisans in Ranthambore, Rajasthan, the skills of creating footwear and its usage within the communities are examined.¹ Emphasis is placed on the process, on how things come into being, as opposed to the finished objects themselves.

In the first part of this article, a description is offered of what is understood by ‘design and making’. Two intuitions are compared: the first is where ‘design and making’ are seen from an external position – ‘the God’s eye view’. In this intuition, design precedes making as a creation in the mind of an agent and is followed by making as an execution in the material. In this article, however, a second intuition is followed, according to which ‘design and making’ proceed in tandem as formative processes. ‘Design and making’ are examined from an internal position, by seeing people amongst the materials of their craft (Ingold 2013).

In the second part of the article, the action research carried out with the Kolhapuri artisans in the South of India, and with the Jutti artisans in the North, is discussed. Both communities use the same material – bag-tanned buffalo hides – to make footwear. Through action research on the making of

footwear, the relation between the craftsman, the material and the tools used in their surroundings, is investigated. Next, the process of making footwear is investigated, starting with the tanning of the raw hides and the properties of the material, not with the finished product.

In the third section the focus is on the interactivity of the research. Can one talk about reciprocal ethnographic knowledge exchange? Hal Foster (1995) is skeptical about the effects of the pseudo-ethnographic role set up for the artist: ‘For the setup can promote a presumption of ethnographic authority as much as a questioning of it, an evasion of institutional critique as much as an elaboration of it.’ Are Foster’s misgivings about role set up, whereby the artist poses as an ethnographer, also applicable to the designer? And what is the impact of anthropology and action research for the designing artisans and for a comparative study of design? In my approach, the apprenticeship of the anthropologist as a designer, working alongside the artisans, assumes a dialogue and an interactivity which result in shared ethnographic power. Inspired by the New London Group’s (1996) programmatic statement for education, it is argued that ‘this reflective practice helps to denaturalise and make strange what we have learned and mastered’. In conclusion, the article shows that mutual control (Pinxten 1997) is possible and gives an example of what design anthropology can mean, i.e., being more than an after-the-fact description of what is observed.

Work in progress

Are design and making interchangeable? They are indeed interwoven. They influence each other during the process of working with the material and thinking about the work. Whenever design is discussed here, it includes the use of the tools, materials and thought processes involved in making the footwear.

Following the doctrine of hylomorphism, first formulated by Aristotle, making and design involve the bringing together of form and matter. Over the centuries this model became increasingly unbalanced, as form came to be seen as imposed by an agent with a particular idea in mind, while matter, thus rendered passive and inert, became that which was imposed upon (Ingold 2011). The design as idea is an immaterial form to be imposed on a material substance. The philosophical term and intuition *God’s eye view* offers a broader frame to this doctrine. In the intuition of the *God’s eye view* we humans look upon things, people, the earth and, indeed, the whole universe as if we were able to take the point of view of the only outsider in the Western cultural and religious tradition, i.e., God. Of course this need not be a universal human intuition –in fact, anthropologists know this is rather specific to the Western tradition (Pinxten 2010). In this first intuition, design, followed by making, are rendered context-free and objective products. According to Tim Ingold (2013), making, in terms of this intuition, is thought of as a project.

In what follows, ‘design and making’ are observed from another angle, a second intuition. Here, neither design nor making comes before the other: rather, both emerge together as twin outcomes of the process. Making is deemed a process of growth (Ingold 2013), while the outcomes of the making process are described as ‘things’, not ‘objects’. In the last two decades, different authors have emphasized this process of growth, focusing on a range of materials. For example, in his essay ‘On weaving a basket’, Ingold (2000) dissolves the binary between making and growing. Baskets are made of long, flexible sticks which have to be bent into shape. The weaver begins with a spiral and the basket slowly develops in the weavers’ hands. The idea of applying a form does not fit well in this scenario. The material is not just formed, it is also formative. Suzanne

Lee (2012) uses ‘biocouture’ to look at the growing aspect of material, with her focus on cellulose which has been around for millennia. ‘Biocouture’ transfers materials from the natural world in order to explore their potential and determine whether they can work in different contexts. The bacteria, and the cellulose that results from it, are grown in sheets under controlled conditions in a laboratory setting. But eventually they can also grow into other shapes. The bacteria and the material outcome are natural, recyclable and biodegradable. The aim is to grow as much of it as you need, while using minimal resources.

Let us now turn to the action research which explores the relations between the artisan as anthropologist, the anthropologist as artisan, and the material. The engagement with the material used for making the footwear will be under focus. The perceived object of appropriation in this case is the vegetable-tanned buffalo hide and the connected skills of working with the material.

100% bag tanned: matter in movement – a description

Following the second intuition, a description follows of the material used and the products made during the action research, carried out between December 2009 and March 2010, and between December 2012 and February 2013.

In between the two research periods I maintained regular contact with both groups of artisans. The fieldwork with the Kolhapuri artisans in Athani, a village in the south of India at the border of Karnataka and Maharashtra, involved 20 artisans. The fieldwork with the Jutti artisans of the village Kundera near Ranthambore, Rajasthan, involved four artisans. In addition to skilled practice, i.e., knowing by doing, information was gathered through observation, interviews with the tanners of the hides, the artisans of the two

footwear communities, the managers of the communities, and from the technical reports of the Central Leather Research Institute (CLRI).²

In India, the small-scale footwear industry³ employs the traditional cobbler caste, known locally as chamars. Individual shoemakers and shoemaking families continue to supply footwear to the local community and their own families, as well as for export purposes. Most artisans work in family-based establishments, transferring skills and knowledge from one generation to the next. The men are skilled at making the soles, while the women make the uppers and do hand-stitching.

— *In front of their houses sitting on the ground they are making the footwear. Tools and leathers are displayed. Small children play with the tools. A small boy, about three years old, is trying to put a wooden shape in a shoe that is used for giving the vamp a good shape. Meanwhile his father is working on a jutti, keeping an eye on the boy. (Observations from Kundera village, 2013)*

I worked with the Kolhapuri artisans of Toehold, a not-for-profit organisation in Athani, Karnataka, which promotes the empowerment of rural women, with an emphasis on social accountability. In Rajasthan I worked with the Jutti artisans of Dastkar Ranthambore, a grassroots social enterprise dedicated to providing an alternative source of income for men and women living around Ranthambore National Park. The artisans participated on a voluntary basis. During the fieldwork, the manager(s) of the not-for-profit organisations Toehold and Dastkar were available for linguistic and other practical assistance. For logistical reasons I worked at the organisations' central building, rather than in front of people's houses.

— *These villages are divided into distinct neighbourhoods. Around the temples you mainly find the Brahmans (priests), in another district you find the Kshatriya (land owners and people having government functions), next come the Vashiya (traders), towards the periphery of the village you find the Shudras (peasants, metal smiths, cowherds etc.). The ones who work with leather (like butchers, tanners and shoemakers) are below all other crafts and live and work on the outskirts of the village. Separated from the Brahmans, the Vashiya and the Shudras, the cobblers in Kundera live on the other side of the big road. The tanning activity stopped in their village a few years ago. They get leather from another village belonging to their community. In Athani the tanning activity still goes on, but they only tan a few hides a week. You find the tanning community two kilometres further away from the cobblers, outside the village. (Fieldwork notes from Athani 2010 and Kundera 2013)*

In the next section, the story of vegetable-tanned buffalo leather in two communities in India is explored. What happens when you treat the hide in a particular way? What happens to the hide during different seasons, e.g., rain vs. dry season? I found that the material –in this case, the hide– is far from a static entity with fixed attributes.

**Two cases, one material:
the manufacture of bag-tanned
buffalo leather**

There is no such thing as leather. There are many types of leather, and even coming from the same animal, no two hides are the same. This is especially true for bag-tanned leather, a rural vegetable tanning process –depending on the level of engagement, the hide will be suppler or stiffer. The tanners and artisans know what happens if they treat

the hide in different ways. Even when human intervention stops, the hide still grows and undergoes changes due to weather and light, being worn or not worn.

Water buffaloes, which are used for dairy production throughout India and other parts of Asia, provide tough and useful hides. In these particular communities, the buffaloes are not slaughtered for meat consumption –only when a buffalo dies of natural causes is its leather used for footwear and other products. The tanning of the hides is traditionally done by the tanner community, which is geographically situated in the same neighbourhood as the cobblers and is interdependent on them. The tanners and cobblers are Hindus.

A local manager, a Brahman, declared:
— *The livelihood of the artisans depends on the leather and thus they have to touch all kinds of leathers. I prefer to work with buffalo leather, but if there is no alternative I have to work with cow-hides. You know that if it is dead you can use it, there is no problem. But do not kill it because you need it. Even the tanners do not kill the animals. The ones who kill, the slaughterers, come from another community. Mostly the slaughterers come from the Muslim community and for them the cow is not holy as it is for Hindus. And also, the buffalo is the carrier of Yama, the Lord of death. So it is in the psychology of the people, that the use of buffalo skin is not so bad. (Mutalik, pers comm., 2010)*

After the raw hides have been cleaned of blood and dirt, they are put in a bath containing a lime solution. The hides become plump and swollen, and after ten days they are ready for dehairing with a knife. Once the dehairing is done the stock is ready for vegetable tanning, which involves colouring and suspension. The colouring of both flesh

and skin sides is done in a bath consisting of babul bark, myrobalan nut and water. This colours both sides, but the central part of the skin is left untanned. For tanning the middle part, the hide is stitched with strong sisal fibre into a cylindrical bag with a narrow opening at the neck. The bag is filled with a mixture of babul bark and crushed myrobalan nuts, and suspended over wooden logs. Tanning liquor, made of bark and nuts, is poured into the bag at frequent intervals. The more tanning material and the greater the percentage of babul bark and myrobalan nuts, the softer the leather becomes. The leather produced with higher levels of babul bark alone is firmer and more durable, but also harsher and darker in colour. The whole production, raw hide to tanning, takes about 35 days. The tanning does not make use of any synthetic industrial materials and is eco-friendly. The waste generated through the tanning process is used as compost in agriculture. However, large quantities of water are used for the tanning, giving it a high water footprint.

According to the artisans and the Central Leather Research Institute (CLRI) in India, bag tanning is likely to disappear by the next generation, for a number of reasons. Primarily, the artisans are shifting to other professions due to the high cost of tanning materials and raw hides, as birth and survival rates among the buffaloes have fallen over the years. In addition, the local tanners have other job opportunities due to the policies of the Indian government, which encourages higher education and gives preferential access to jobs (according to a quota system) to lower-caste people (scheduled castes). Further, the government recently lifted a ban on the export of raw hides,⁴ thus increasing the demand. As a result, it is difficult for local tanners to obtain raw hides, and consequently for cobblers to access bag-tanned leathers. In addition, the regional government of Karnataka State implemented a ban on cattle slaughter by introducing the

Karnataka Prevention of Cow Slaughter and Preservation Bill in 2012. In comparison, the previous law of 1964 allowed the slaughter of cattle if they were over 12 years of age, or were no longer fit for breeding. However, recent newspaper articles (May 2013) have reported that the new government is looking to reinstate the law of 1964.

The pictures shown here, were taken in 2010 in a bag-tanning unit in Athani. Of the ten bag-tanning units in the surroundings, only two are still active.

Two cases, one material: Kolhapuri chappals and the juttis

Kolhapuri footwear

The origin of Kolhapuri chappals can be traced back to 12th century–rule of King Bijjal of Bidar District and his Prime Minister Basaveswara who wanted to create a caste-less society and remove the stigma associated with Chamar community (Mahadevi 1980).

Kolhapuri footwear originates from the districts of Karnataka and Maharashtra and is worn all over India. It is a sandal with an open structure at the back. The chappal features a leather sole, two side flaps (kanwali), an instep band and a toe strap. The outsole, insole, upper, toe ring and heel are sewn with leather threads from the tail of the buffalo. Kolhapuri refers to the city Kolhapur, but the geographical area of production is wider and also includes Athani. Characteristic of the Kolhapuri chappal is the initial stiffness of the outsole. Only the parts touching the ground become more supple. The other parts retain their stiffness and ensure protection of the foot on the clayish rocky terrain. The summer months in this region are extremely hot, with temperatures reaching up to 40 degrees Celsius.

Jutti footwear

Jutti is a Hindi/Urdu word for a shoe with

a closed upper attached to a sole. The jutti is closely related to the mojari which was introduced during the Moghal conquest of India in the early 16th century (Jain–Neubauer 2000). Juttis are usually made of leather, but can also be made out of softer materials such as silk. The production is still concentrated in central and northern India. Juttis come in many variations, depending on the regional traditions, the time period and the skill of the shoemaker. They are intrinsically related to the environment and the available materials. The sewing of the different pieces is done with a cotton thread. Juttis have no left/right distinction and are always flat. A last is inserted and left for a few days until the vamp attains the desired shape.

In Kundera, the juttis are made with leather, having a closed counter. The leather of the outsole is derived from buffalo; cow hides are usually used for the uppers. The style of the juttis in Kundera is rather heavy, with a round nose. In contrast to Kolhapuri footwear, the outsole is more flexible, which makes it easier to hand-stitch the full vamp to the outsole. The artisans of both communities wear their own footwear on a daily basis from the age of six years onwards –prior to that age, they usually go barefoot. They claim there is no better footwear than their own, for their environment. In Athani, no better option than a sandal made out of bag-tanned leather is available to absorb the heat and moisture of the climate. The jutti also has good breathing capacity, being cool in summer and warm in winter. The soles are strong and protect the wearer’s feet from injuries.

Looking at the different stages of the making process and at the use of buffalo hide, it is evident that different parts of the animal are used for different purposes: the tail is used as thread for hand stitching, and the horns for polishing the leather. The leftovers are used in-between the layers of the heel parts, while the smaller pieces are sold to farmers

Dehairing the hide
Hides stitched together into a cylindrical bag and filled with a liquid
© Kristiaan D'Août



Tanning unit in Athani
Dry hides ready for use
© Kristiaan D'Août



to use in fertiliser. In both cases the footwear is handmade without using harmful adhesives. Mass production is therefore not possible. The artisans make maximum use of the materials and any wastage is recycled, which speaks of environmental consciousness.

The outsoles probably enhance proprioception, the sense of one's own body in the environment, while at the same time protecting the wearer against injury (D'Août and Willems 2011).⁵ From a biomechanical point of view, good proprioception is needed as input for the body to adjust to different positions and surfaces, and to control balance and stability. In the context of this article, the footwear is considered part of an unbroken proprioceptive loop that runs out from the brain of the wearer, through the feet and into the surface s/he walks on, and back again, allowing the individual to monitor and adapt the pattern of his/her gait. The following are sample testimonies on the environmental impact and comfort of the footwear:

— **Artisan 1:** First we try to fix them; we add an extra sole and repair them. If too old we throw them out. If you put them in the ground it takes three months and they start to decompose. Then they become fertilisers. The waste after shaving and cutting is gathered and sold to the farmers for their fields. (*Sahadew, pers comm., 2010*)

— **Artisan 2:** The bigger leftovers are used in the heel part. The smaller pieces of shaving are mixed with the ground to grow our onions. It is very good to grow onions you know. (*Prahalaad, pers comm., 2013*)

The footwear is used throughout the year, also during the monsoon. After the heavy rains the footwear dries in the sun and castor oil is applied to make it soft again and to remove wrinkles. The castor oil improves the

durability of the footwear; it protects your feet from minor cuts and scratches and prevents fungal growth on the footwear. People declared that, wearing the footwear gives coolness to the eyes because you don't sweat in the footwear. According to them it is the combination of the bag-tanned hide and the oil that ameliorates eye vision and prevents irritations of the eye. (Based on interviews, 2010)

Action research: 100% bag tanned

100% bag tanned is a collaboration with the artisans to make footwear using only bag-tanned buffalo leather and their specific skills. The aim is to integrate the artisans into the design process, both as viewers and as makers. Making new models is a means of becoming engaged with the artisans and rethinking designs. During the action research several wearable products and a select variety of products were created for a limited edition. Because of the length of the reports and the exploratory nature of this article, what follows is merely a synopsis of the work done in the two communities. We work together on the floor of the organisations' facility, with tools and leathers displayed before us. We squat on the ground while cutting the leather, and sit on the ground while hand-stitching the pieces. This arrangement allows for interaction. Skill observation and training take place simultaneously. Being seated gives the artisan the freedom to use his/her feet to hold a piece in position. We look at the sandals and shoes, comment on the sizes and the quality of the leather. We compare outsoles and foot shapes and adapt them to each other. For measurements and sizing the hands are usually used. We discuss and explain sizing systems, proportions and ideas for closing the sandals – this would mean not having to depend on external suppliers. The bag-tanned leather is first wetted for easy cutting. The leather is cut perfectly with a half-moon knife. On the ground there is a



wooden log on which to cut the leather, and a stone for shaving the sides, to remove flesh from the inside when a piece is too thick. The ability to improvise in relation to the uneven thickness of the hides and knowing which knives to use (and how) comes from years of experience. While still damp, the leather is hammered heavily and repeatedly to make it even, flat and pressed. The soles are then polished by rubbing them with a buffalo horn. The hand-stitching on the outsoles is principally done by the women, mainly in their homes, although for this collaboration the artisans explained this process in our location. While creating the footwear we investigate the possible designs that can be created using the smaller pieces of leather. For the first time the artisans make different types of leather bracelets –woven and non-woven.

The material opens up other possibilities in terms of use, function and form (Willems, Van Gogh and Pinxten 2012): from buffalo to tanned hides and then to footwear or bracelets and finally as a fertiliser; the material keeps transforming.

Action research: a reflection

What impact do anthropology and action research have on the designing artisans and on design anthropology? By dwelling in the actions of the artisans, i.e., looking at the processes of creation from an insider perspective, I aimed to gather the tacit knowledge necessary to make footwear, while arriving at a better understanding of the context of the material and of the products.

As regards the socio-economic conditions of the artisans: since the 12th century, various reformers in India (including Gandhi and Ambedkar) have tried to bring greater dignity to chamars and other untouchable castes. In 1913, Mahatma Gandhi (in Tendulkar 1951) wrote to Jan Christian Smuts, State Attorney and later Prime Minister of South Africa:

— *I am mostly busy making sandals these days, I have already made about fifteen pairs. When you need new ones, please send me the measurements. And when you do so, mark the places where the strap is to be fixed, that is on the outside of the big toe and the little one.*

In making footwear, Gandhi demonstrated a profound understanding of the value of the leather craft. By learning the skills of one of the lowest castes of labourers, the chamars, and by dealing with a material that was ritually polluting, Gandhi became a prominent role model for egalitarianism and self-reliance – something he hoped would influence future Indian societies. The artisans, though, do not really become shoemakers by choice; rather, it happens through lack of choice (Venkatesan 2010). Almost all of the artisans in these two communities practice their profession in order to make a living, but they want a different future for their children. Although this household industry allows for a certain degree of freedom, the artisans still do not value their profession highly.

As a designer/researcher with an interest in their artisanal skills, however, I value the work of the artisans and their products. In *The artist as ethnographer*, Foster (1995), writes: ‘So the quasi anthropological “artist” today may seek to work with sited communities with the best motives of political engagement and institutional transgression only in part to have this work recoded by its sponsors as social outreach, economic development, public relations or art.’ What Foster notes about the anthropological artist can also be said of the anthropological designer. In my research, however, I avoided this trap by ensuring that the artisans and the researcher were equally close to the object of study. The researcher was not seen as external anthropologist but as a foreign designer, having the same interest in the skill of making footwear and working with leather. Rather than the cultural or ethnic ‘other’,

the perceived object of appropriation was the material, along with the skilled practice necessary to make the footwear. This links with the second intuition, where making and design are viewed from an insider perspective as transcending the pure opposition between researcher and artisans. It is through the contextualisation of the skills that I avoided only partially engaging with the community. Many organisations and companies are, however, interested in preserving skills, for different reasons. The main aim of these developmental interventions was to ensure that the footwear will continue to be made. It is considered important for the shoemakers who would otherwise lose their livelihood, and it is aimed at preserving a valuable element of their material and cultural heritage (Venkatesan 2009). In addition, the Leather Council of India is interested in preserving these skills and in skill-mapping, as handmade products are increasingly deemed luxury items that bring economic benefits.

The focus of this study was on what it means to make things, in various contexts and using different practices, rather than on preserving a particular set of skills. It is highly likely that the use of bag-tanned leather will disappear – in the cases mentioned here – within the next ten years, and that pressed and other leathers will replace it. Local tanning activities will cease, tanners will move into other jobs, and the knowledge connected to their artisanship will be preserved only in documents and visual records. The same is true of the artisans making the footwear. If there are openings in other jobs or in higher education, they will not hesitate to switch careers. My enthusiasm for the craft is decidedly greater than that of the artisans themselves, but I do not live in their communities, nor do I face the everyday struggles they do. Still, the way this footwear is made offers a different perspective on design, and I consider this footwear a luxury accessory ‘avant la lettre’, for four reasons: 1) clearly

the material is treated in a respectful way; 2) neither the tanning nor the making put undue pressure on the environment; 3) the products also have an afterlife as fertiliser; and 4) as regards the biomechanics: the footwear respects human anatomy. In the end, material, soil, climate and feet are all in balance.

What can anthropology and action research contribute to a comparative study of design or design anthropology? According to Wilfried van Damme (2006), the discipline of anthropology can make three main contributions to developing a global perspective in the study of art and aesthetics. The first lies in its engagement with the conceptual, epistemological and methodological issues that arise when dealing with phenomena in various cultural worlds. The second lies in the range of cultures and regions on which to base our analyses. The third lies in anthropology’s empirical-inductive stance, its contextual emphasis, and its intercultural comparative perspective.

For the discipline of design anthropology the emphasis is on the third contribution and the use of action research as an active method of investigation. The material and the skills make a bridging contribution. Analysing design processes in a comparative way, with the people involved, helps researchers rethink design and allows them to analyse it from different perspectives.

Conclusion

This study shows that design anthropology is more than a mere description of manufactured products. Design anthropology aims to explain the relation between human beings and ‘ongoing things’. The argument made here, is that a skill is embedded in a larger corpus of social knowledge of the value of the skill, based on ideas about the body, gender, the environment and local resources. Acquiring, utilising or depending on a skill positions individuals/groups in particular ways, which are not necessarily of their choosing. By focusing on the processes of design formation within a specific environment, it is possible to avoid the risk of ‘pseudo-ethnography’. Empowering participants requires the sharing of creative processes as equals, rather than as exclusive knowledge coming from the researcher/designer. The aim is to foster creativity, ownership and empowerment, rather than to appear as a final authority on creativity. In action research the designers –including both artisans and researcher– are non-possessive of the outcome and share authorship, therefore the project can develop a life of its own. Design anthropology is founded on engagement and is always an anthropology ‘with’ rather than ‘of’ the people. Applying anthropology ‘with’ implies learning with different people during our investigations and involves different kinds of experimental activities, tools, theoretical concepts and materials (Gunn and Donovan 2012). Using action research as a method, starting with the material itself, implies that the familiar becomes strange and that ‘non-obvious’ aspects are viewed against a broader background, which results in an improvement of ideas and, as a consequence, new design.

The footwear described here is truly a luxury item. Education for good design begins with an analysis of the entire history of the material, not with its particular state when it is used to manufacture a product. The

before-and-after life of the materials is of critical importance when working to achieve sustainable design.

— **Acknowledgements**

My sincere gratitude goes to the artisans and the management of Toehold Artisans Cooperative and of Dastkar, for their enthusiastic participation and extensive support throughout this project. A special thanks to Ms. Madhura Chatrapathy and Mr. Raghu of Toehold, Mrs. Ujwala of Dastkar and Mrs. Devika Krishnan for facilitating all logistics and communications between me and the artisan communities. My deep gratitude goes to Mr. B.N. Das of CLRI for his support and the technical expertise he shared with me. In addition, I thank Mr. Ravi Arumbakam for the long discussions we had over the last ten years on Indian culture and on current society. Thanks also go to Professor Tim Ingold for his inspiration and guidance regarding the final draft of the article.

— **Notes**

- ¹ The article is part of a broader PhD project ‘Future Footwear’. The interdisciplinary research analyses gait patterns over four conditions: 1) walking barefoot on a natural substrate; 2) shod walking on a natural substrate; 3) walking barefoot on a hard substrate; and 4) shod walking on a hard substrate. To measure the differences a) plantar pressure recordings (RSscan Footscan); b) videography of the gait and standardised photography of the footwear; c) registration of anthropometric variables; d) surface EMG (electromyography) measuring muscle activity; and e) accelerometry (feet-ground impact) are used. To record the data, Biometrics DataLOG is used. DataLOG is a fully portable subject-worn programmable Data Acquisition Unit allowing the user to collect data from a wide range of sensors, including Biometrics goniometers and EMG sensors.
- ² CLRI is a governmental organisation in Chennai, India, dedicated to research, development, education and training in the Indian leather industry (<http://www.CLRI.org>).
- ³ India also has large-scale industrial footwear manufacturing. The leather industry holds a prominent place in the Indian economy. India is the second largest producer of footwear and leather garments in the world (Council for Leather Exports, India, www.leatherindia.org).
- ⁴ Lifting of the ban on exporting raw material. ‘The Seetharamaiah Committee recommendations of 1972’.
- ⁵ Preliminary analyses of the Kolhapuri footwear suggest that plantar pressure distributions differ relatively little between barefoot and shod walking. In addition, the centre of pressure trajectories and the vertical ground reaction forces are qualitatively similar. This means that indigenous footwear has little impact on normal foot biomechanics.

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BIOMECHANICS



BIOMECHANICS

Walking on natural and artificial substrates:
The effect of indigenous footwear

Catherine Willems ¹
Gaetane Stassijns ²
Wim Cornelis ³
Kristiaan D’Août ^{4,5}

- ¹ Department of Design, University College
Ghent, Belgium
- ² Department of Physical Medicine and
Rehabilitation, University Hospital Antwerp,
Belgium, University of Antwerp, Belgium
- ³ Department of Soil Management,
Ghent University, Belgium
- ⁴ Department of Musculoskeletal Biology,
Institute of Ageing and Chronic Disease,
University of Liverpool, UK
- ⁵ Department of Biology, University of Antwerp,
Belgium

Article to be submitted to *Gait and Posture*

Abstract

We investigated biomechanical implications of walking with Kolhapuri sandals compared to barefoot walking on a natural and on an artificial substrate (that is, four conditions). The artificial substrate is stone, the natural substrate is compacted sand (clayish substrate). The study involved ten healthy adults (males and females) from Athani, a village in Karnataka, India. Each subject walked 20 steps in the four conditions, and data were collected (with a Biometrics data logger) from (1) a heel-mounted 3D-accelerometer recording peak impact at heel contact, (2) an ankle-mounted 2D-goniometer (plantar/ dorsiflexion and inversion/eversion), and (3) sEMG electrodes at the m. tibialis anterior and the m. gastrocnemius medialis. Quantitative analysis of the data suggests that substrate has a greater effect on the measured variables than footwear. For peak at heel contact the fixed effect of substrate was significant (p=0,00). Acceleration peak on the natural surface is approximately 25% higher than on the artificial surface, regardless of whether one is barefoot or with the footwear.

Kinematically, the ankle is more dorsiflexed at heel strike on a natural substrate versus an artificial substrate in both shod and unshod conditions. The plantar flexion at toe-off is more extreme when shod, both on the natural and the artificial substrate. Total eversion between heel strike and midstance is slightly higher barefoot and on a natural substrate than in other conditions. Total EMG does not differ between conditions for the m. gastrocnemius medialis, but does for the m. tibialis anterior, being lowest barefoot on a natural substrate and highest shod on an artificial substrate. Stance duration is higher on the artificial than on the natural substrate for both footwear conditions. Kolhapuri footwear seems to alter foot biomechanics only in a subtle way, its effect being similar or smaller than that of the substrate. These indigenous shoes might therefore be considered “minimal” and future research will compare them to modern, Western “minimal footwear”.

Keywords:
gait
kinematics
impact
electromyography
footwear
Kolhapuri
India
substrate

Introduction

Locomotion is crucial for humans, which have uniquely evolved into striding bipeds with a highly efficient gait. Walking and running ultimately boils down to the mechanical challenge of generating an impulse by means of the interaction between feet and the ground. The nature of this foot-ground interaction has remained the same during most of human history: barefoot on a natural (but highly variable) substrate. Only very late in their evolution, long after they had become anatomically modern (D’Août et al., 2009), humans became habitually shod and began using artificial substrates.

Archaeological evidence suggests that footwear might date back to the middle upper Palaeolithic, ca. 25 thousand years ago (Trinkaus, 2005). Throughout most of its history, however, indigenous footwear probably remained very basic and was made from plant fibres or a simple leather construction as seen, for instance, in ancient Egyptian (Veldmeijer, 2009a; Veldmeijer, 2009b; Veldmeijer, 2009c; Veldmeijer, 2012) and Roman (Sesana, 2005) footwear. The daily use of constricting footwear, with features such as a firm heel cup, arch support, cushioning, and motion control, is a recent phenomenon. In running shoes, for example, development of such features mostly occurred since the 1970s (Shorten, 2000), (Lieberman et al., 2010), with increasing interest in barefoot running and in various types of more or less “minimal” shoes only during the last decade –for comprehensive overviews of this development, see dedicated volumes of Footwear Science (vol. 5(1), 2013) and the Journal of Sport and Health Science (vol. 3, 2014). We note that various types of highly decorated footwear have long existed for cultural purposes rather than a functional one in biomechanical sense (Willems & D’Août, 2013; Riello and McNeil, 2006), but these were not owned or worn on a daily basis by a large part of the population.

Footwear and substrate interfere mechanically with each other at the foot-ground interface and can thus be expected to have a major influence on the mechanics of gait. A large body of work has focused on this influence for running (e.g. Altman and Davis, 2012), but the effects on normal walking in healthy subjects have received relatively little attention.

With regard to footwear, it has been suggested that habitual use of footwear can cause pathological changes (Hoffmann, 1905; Zipfel and Berger, 2007; Fong Yan et al., 2013) and that (in native populations) a habitually unshod foot is healthier than a habitually shod foot (Mafart, 2007; Zipfel and Berger, 2007). Causal relationships are difficult to demonstrate, but it has been shown, for instance, that adults who began to wear closed toe-shoes before the age of six had a higher prevalence of flat feet compared to those who began wearing shoes only after the age of six (Sachithanandam and Joseph, 1995) and that shoes can restrict the natural motion of the barefoot and impose a specific foot motion pattern on individuals during the push-off phase (Morio et al., 2009).

Extensive research of running barefoot or in minimal footwear has revealed relationships between changes in footwear and changes in strike pattern (Lieberman et al., 2010; Lieberman, 2012a; Daoud et al., 2012; Lieberman, 2012b; Kerrigan et al., 2009; Perl et al., 2012; Bonacci et al., 2013). The advantages of barefoot running, such as lower injury rate versus different strike types, are still debated (Lieberman et al., 2010; Jenkins and Caution, 2011; Daoud et al., 2012; Hatala et al., 2013b), but it has been shown that barefoot running with a forefoot strike involves a lower impact peak than shod running with a heel strike. Such a relationship is not to be expected for walking, however, since (in healthy subjects) walking always involves a heel strike, and (all else being equal) we always expect a higher impact when barefoot than when shod.

With regard to substrate, harder surfaces have been associated with injuries in running, whereas a more compliant surface can alleviate injuries and enhance speed (Nigg and Yeadon, 1987). Runners can compensate for some changes in substrate stiffness by adjusting leg stiffness (aiming to keep the total stiffness of body and substrate approximately constant), which allows them to maintain similar running mechanics on different surfaces (Ferris et al., 1998; Ferris et al., 1999; Kerdok et al., 2002). For example, walking (as well as running) on loose sand, a natural substrate of low elasticity and high viscosity (dampening), requires more effort but energy saving is still achieved through pendular motion (Lejeune et al., 1998).

Hardin et al. (2004) investigated substrate and footwear during running and found active adaptations to changes in passive mechanical effects. Hatala et al. (2013a) mentioned that more compliant surfaces would likely result in lower impact peaks –if attenuation of impact forces is important for the selection of foot strike patterns, then runners may make smaller adjustment to their strike patterns on more compliant substrates.

In this paper, we set out to explore the influence of substrate and footwear on human walking by studying a population (in southern India) that (a) is used to barefoot as well as shod walking, using basic indigenous footwear on a daily basis, and (b) is used to walking on natural (unpaved) and on artificial (man-made, paved) substrates.

We will compare walking on different substrates and footwear conditions (that is, barefoot or indigenous footwear) and with a focus on kinematics, kinetics (accelerometry), and muscle activity. More specifically, we will compare (1) the main rotations of the ankle joint, plantarflexion/dorsiflexion, and inversion/eversion, (2) the peak acceleration of the foot at initial impact, and (3) the

activity patterns and magnitude of two major external foot muscles, that is, the m. tibialis anterior (a dorsiflexor) and the m. gastrocnemius (a plantar flexor).

We will test the hypothesis that walking on the (hard) artificial substrate, compared to the (softer) natural substrate, will involve higher impact accelerations, faster ankle rotations over a larger range, and a higher muscular activation. The same pattern is expected to exist for barefoot walking compared to shod walking.

Materials and methods

Subjects

Ten healthy adult volunteers were recruited from a local population in Athani, a small rural village in the state of Karnataka, South India (Table 1). All subjects were habitually Kolhapuri (indigenous footwear) wearing adults and walked barefoot during childhood up to approximately the age of 6. The subjects had no apparent foot or orthopaedic problems, and they had a normal gait. The subjects participated on a voluntary basis, were informed of the protocol by a local translator, and gave written informed consent according to the protocols approved by the ethical committee of the University of Antwerp. Prior to the recordings the subjects were weighed and measured and they answered a short questionnaire about footwear habits and recent injuries of feet and ankles. The measurements (not all of which are used for the current paper) were: stature, leg length (greater trochanter to ground during standing), mass, and navicular height during standing (half weight bearing). We also recorded sex and age of the subjects. Throughout the experiments, the managers of the non-for profit organization Toehold (<http://www.toeholdindia.com/>), which employed most of the participants, were available for linguistic and other practical help.

Footwear

Kolhapur footwear, a type of sandal made entirely from buffalo skin, is commonly used in India. The sandal (Img. 1a) –or chappal, as they are locally called– is made out of bag tanned buffalo leather, using babul bark and myrobalan fruits. All parts of the chappal –sole, uppers, and heel– are from this leather. The sandal is characterized by a toe ring and an instep band. Often a toe strap, woven in leather, is attached passing from the instep band to a point adjacent to toe ring on the sole. The instep band is fixed between out- and insole and the toe loop into a slot near the toe. The whole sandal is stitched with a leather rope, taken from the tail portion of the same bag tanned leather. The sole stitching is all around the sole, and no glues are used. The footwear does not compress the feet, has no extra arch support and a very thin heel.

We measured thickness of the Kolhapuri sandals as worn by our subjects at four locations using callipers (all values are presented as the average \pm standard deviation). The medial midfoot region is least prone to wear and, therefore, its thickness reflects the raw material thickness best: it was 9.76 ± 2.86 mm. The heel is more prone to wear and one or more extra layers of leather are usually added: heel thickness was 14.95 ± 6.35 mm. Under the hallux and the metatarsal region, no extra layer of leather is added but there can be substantial wear of the material; thickness was 7.81 ± 2.73 mm and 7.90 ± 2.49 mm, respectively. The thickness of vegetable tanned buffalo leather is about 3 mm and the density is about 0.640 g/cm^3 , which is substantially less than that of natural rubber (about 0.930 g/cm^3). The Kolhapuri footwear used in this study has an average mass of approximately 100 gr for European size 37 and approximately 150 gr for European size 42.

Substrate and footwear mechanical properties

Subjects were tested on two different substrates. The first substrate was made of large flat tiles of hard stone and was considered as extremely stiff for the purpose of this paper (Img. 1a and 1c). The second substrate was a natural substrate in the outskirts of the village. In order to characterise its mechanical properties, undisturbed 100 cm^3 samples of the natural substrate (soil) were taken (we used standard 5 cm deep cores) from the site of the outside recordings during the time of the gait analysis in January 2010. In Athani, the winter is usually dry with temperatures around 20°C Celsius. The samples, measured with the pipette method of Gee and Bauder (1986), had a clay loam texture according to the USDA classification (Soil Survey Staff, 1999). The samples were also subjected to a compression test in which the resistance to compression was measured. This was done with a laboratory type T-5001 penetrometer (JJ Loyd Instruments Ltd., Southampton, UK) on the undisturbed samples using a metal plate with a surface area equal to that of the samples (approximately 20 cm^2) and up to 50 N force. The measured resistance is a measure of the stiffness of the natural surface. Similar tests were performed on a section of leather used to manufacture the sole of Kolhapuri footwear and on a stacked sole placed on top of the soil sample. Results are shown in Figure 1.

We note that these results should be treated with caution and are only intended to give a basic idea of substrate and footwear stiffness. Whereas the sole thickness used was the same as that used in shoe manufacturing, we used a single core type for soil characterisation. Cores with different dimensions could yield slightly different compression in such tests. With this caveat in mind, the results show that the soil is stiffer (but of the same order of magnitude) than the leather sole. Thus, the natural substrate representative for this South Indian region is not considered soft.

Image 1 a: Kolhapuri footwear, b: subject in the field, c: subject on the artificial substrate



a



b, c

Figure 1
 Stress-deformation curves for indentation of samples using a 19.64 cm² round stud. x = deformation(μm); y = pressure (kPa). Regression equations (2nd order polynomial): for the soil + sole sample $y = 10.1219\text{e-}6 x^2 + 0.0155911482 x$; for the soil only sample $y = 2.9631\text{e-}6 x^2 + 0.0060091733 x$; for the sole only sample $y = 11.8267\text{e-}6 x^2 + 0.0026848563 x$. Soil thickness, 50 mm; sole thickness, approximately 6 mm (i.e. two layers of buffalo leather). The slope of the curves is a measure for stiffness of the samples. Note that the soil alone is stiffer than the sole alone. The soil + sole has the lowest stiffness. The dashed line provide an example of results at a stress of 15 kPa. At this pressure, the soil alone yields approximately 650 μm, the sole alone yields approximately 1000 μm and a combined sample yields approximately 1450 μm. Please note that the sum of soil and sole deformation is not an exact mathematical match for the combined deformation, as the three curves result from different experiments, with slight sample variation.

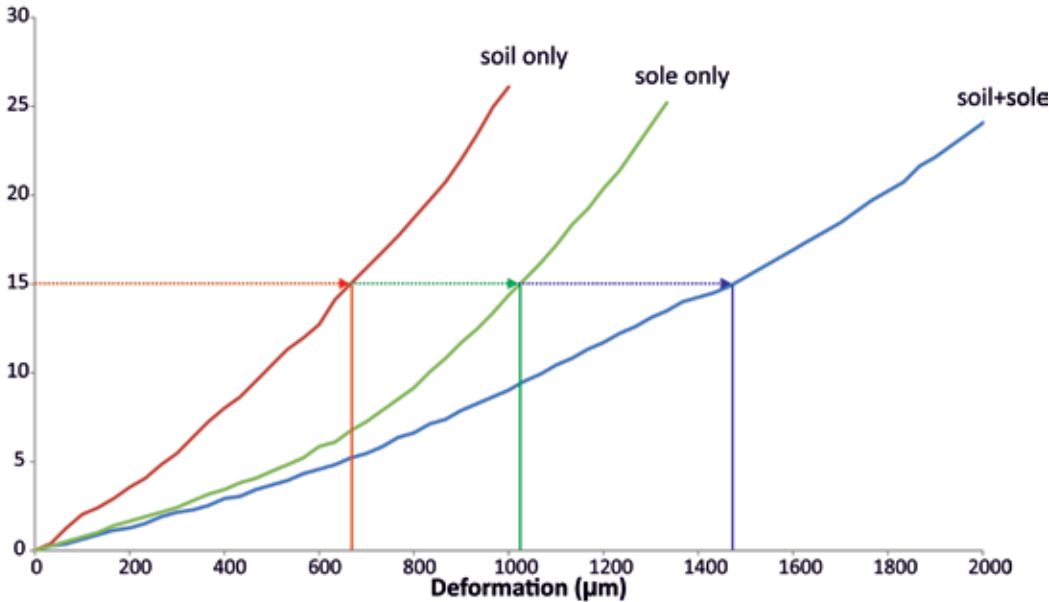


Figure 2
 Ankle kinematics definitions

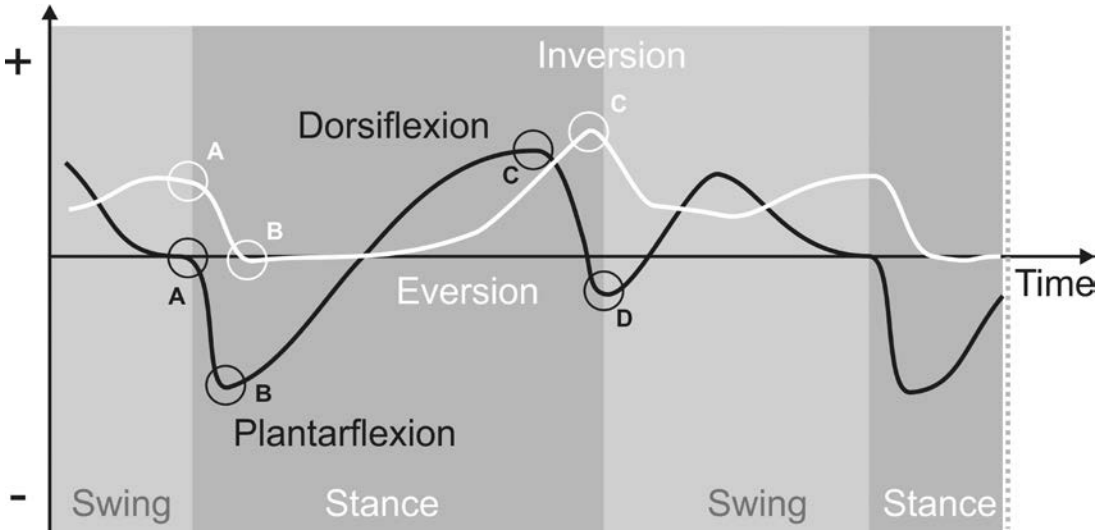
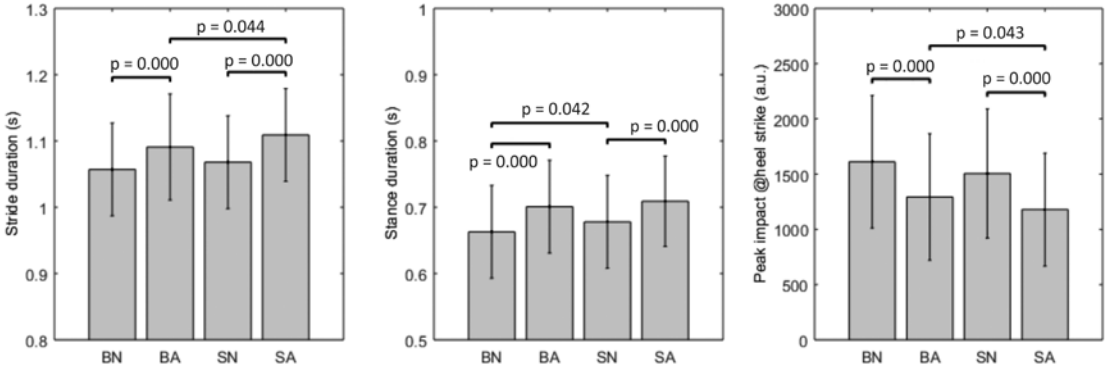


Figure 3
 Spatiotemporal and impact results. From left to right: a: stride duration, b: stance duration, c: peak impact acceleration at initial contact (a.u., arbitrary units).



Instrumentation and data collection

Prior to the experiments, subjects were instrumented as follows (Img. 1c). A 3D accelerometer (Biometrics ACL300) was fitted to the skin on the lateral side of the right calcaneus with double side tape and strapped tightly with strong medically approved tape. A twin axis goniometer (Biometrics SG) was fitted to the skin at the level of the right tuber calcanei, so that one axis measured the simple rotations dorsiflexion/plantarflexion (i.e. rotations in the sagittal plane) and the other axis measured inversion/eversion (i.e. rotations in the frontal plane). In this paper, pronation in the complex motion involves plantarflexion and eversion, whereas supination involves dorsiflexion and inversion. Two surface-electromyographic (sEMG) electrodes (Biometrics SX230) were attached to the skin overlying the right m. tibialis anterior and the m. gastrocnemius medialis. A neutral electrode was worn on the wrist. All data were fed stored as text files on a belt-mounted Biometrics DataLog unit and transferred to a PC for analysis after the full set of experiments. Data acquisition rate was 1000 Hz.

During the experiments, the subjects walked at a self-selected, voluntary speed in four conditions, after several habituation trials before each condition. The four conditions were: Barefoot on the Natural substrate (BN), Barefoot on the Artificial substrate (BA), Shod on the Natural substrate (SN), and Shod on the Artificial substrate (SA). All equipment remained on the subject throughout the experiment, which was possible because the footwear considered here has no heel strap.

For each condition, subjects walked back and forth several times over a distance of approximately 10–15 m. Strides for analysis were from the middle, steady-state sections (discarding the initial and terminal three strides), yielding approximately 20 steps per subject per condition. The complete data

set consists of nearly 800 steps for which all data types are available, except for the sEMG data of subject 10 because of a technical failure.

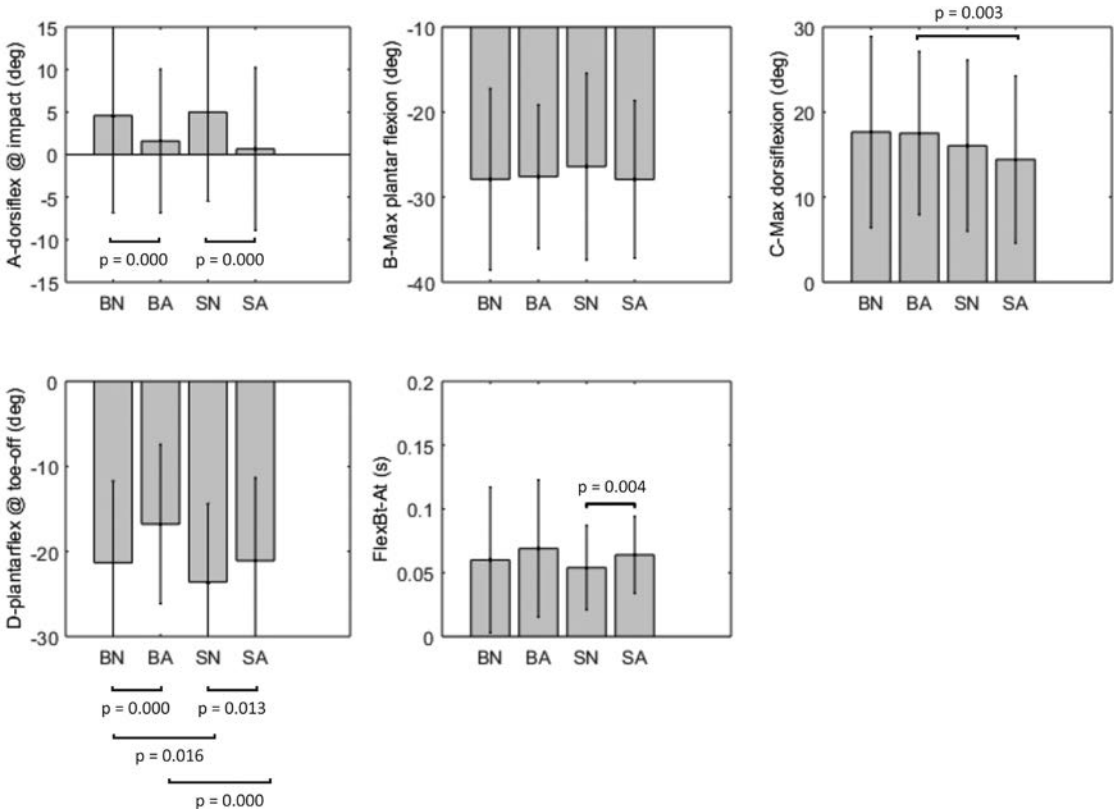
Lateral –whole– body video recordings were made at 50 fps for the trials on the artificial substrate using a full-HD video recorder. Spatial calibration was performed using tape markers on the ground spaced at 1m intervals. In addition to the walking trials, a static standing trial was recorded for each subject.

Analysis: spatio-temporal gait and impact

Speed was measured for the trials on the artificial surface by dividing the distance covered in three full strides (as seen on the calibrated lateral-view recordings) by the corresponding duration. Stride duration was measured as the time between two consecutive strikes of the right foot using the accelerometer signal, as this yielded a consistent sharp peak at initial ground contact. Stance duration is the time from heel contact to toe off (i.e. the time from A to D on the plantarflexion-dorsiflexion plot fig. 2). The duty factor is expressed as the percentage of time the foot is on the ground, that is, stance time/stride time (x 100%).

An Analysis of Variance (ANOVA) revealed that there was a significant interaction between the factors Subject and Condition (shod versus barefoot). The factor condition alone showed no significant differences with speed; moreover, the speed difference between footwear conditions was very small (shod: 1.27 ± 0.1m m/s; unshod: 1.30 ± 0.14 m/s). Because of these results, we will not deal with speed effects in this paper. The speeds that we measured closely reflect the normal range of walking speeds and also closely match speeds for minimal energy expenditure (see e.g. Zarrugh et al. , 1974) as well as a walking speed often imposed in controlled settings (e.g. Zhang, 2013, 1.3 m/s). Impact was assessed as the magnitude

Figure 4
Plantarflexion-dorsiflexion results (according to Fig. 2). From left to right a: value at initial contact (“A”), b: maximal plantarflexion (occurring in early stance) (“B”), c: maximal dorsiflexion (occurring in late stance) (“C”), d: value at toe-off (“D”). Note that all values are relative to static standing posture.



of the vector sum (that is, using the x, y, and z components) of the acceleration peak at initial impact, in order to compensate for small differences between accelerometer positions between subjects.

Analysis: ankle kinematics

All ankle values are relative to static standing in order to compensate for slightly different mounting of the goniometer between subjects. For statistical analysis, we selected several landmark points from the continuous angular measurements. Plantarflexion-dorsiflexion values were measured at initial contact, at maximal plantarflexion (occurring in early stance), at maximal dorsiflexion (occurring in late stance), and at toe-off. Ankle inversion-eversion angles were measured at initial contact, at maximal eversion (occurring in early stance), and at maximal inversion (occurring in late stance). We also measured the duration of initial fast eversion following initial contact and the duration of the slow re-inversion during stance.

Surface electromyography

Raw sEMG data (in arbitrary units) were high pass filtered (25 Hz); (Hof et al., 2002) and rectified. Subsequently, the time series were normalised to one stride, so that average curves could be plotted with standard deviation (see Fig. 5). Next, the magnitudes were normalised enabling a comparison of the pattern of muscle activation between conditions. Total sEMG of the medial head of the m. gastrocnemius (GM) and the m. tibialis anterior (TA) was calculated by numeric integration of the non-normalised data in order to compare the total amount of muscle activation between conditions.

Statistical analysis

The data were analysed with a one way repeated measures MANOVA for each dependent variable. Significance was accepted for $P < 0.05$.

Results

Spatiotemporal gait

Average stride duration varies from 1.06–1.11 s between conditions (corresponding to stride frequencies of 0.90–0.95 Hz) and differs significantly between the natural and the artificial substrate regardless of footwear condition, with the artificial substrate involving a longer stride duration (Fig. 3a). Stance duration also differs between substrates, both when barefoot and when shod (Fig. 2b), with longer average stance durations on the artificial substrate. When barefoot the Duty Factor is lower on the natural substrate (62.8%) than on the artificial substrate (63.9%). This 1% difference has a significance rate of 0.039. No further significant differences between the other conditions were calculated. We also note that barefoot walking on the artificial substrate involves a stride duration that is slightly shorter than for shod walking (albeit $p = 0.044$). On the natural substrate we note a shorter stance duration for barefoot walking ($p = 0.042$).

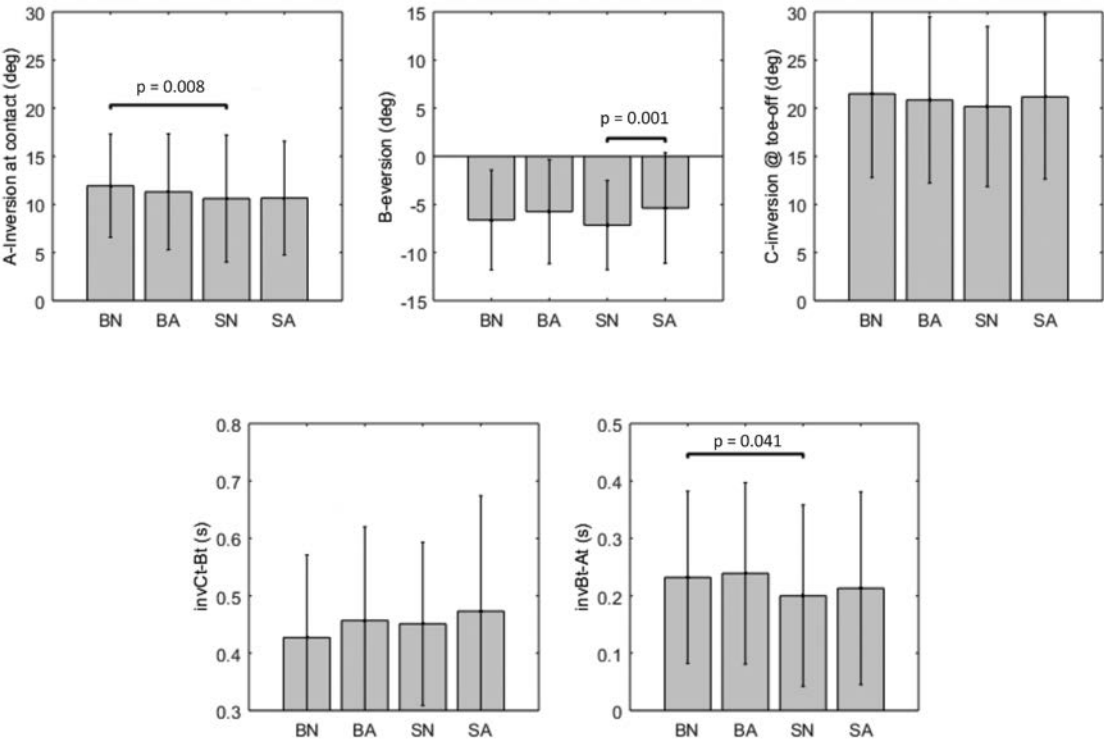
Impact acceleration

Initial impact is associated with relatively high and clearly recognisable accelerations across conditions. Peak impact acceleration at initial contact, which in our experiments is always with the heel, differs most clearly between substrates, with the artificial substrate having lower values in both footwear conditions. Differences between footwear conditions are relatively small or absent (Fig. 3c).

Ankle kinematics: plantar/dorsiflexion

The general pattern for ankle plantarflexion/dorsiflexion is the same for all conditions. The ankle lands at an almost neutral angle (compared to static standing) and then quickly plantarflexes by approximately 25–30°. This is followed by a slow dorsiflexion phase, when the body pivots over the stance foot and ends up being dorsiflexed

Figure 5
Ankle inversion-eversion results (according to Fig. 2). Fromleft to right a: value at initial contact (“A”), b: maximal eversion (occurring in early stance) (“B”), c: maximal inversion (occurring in late stance) (“C”), d: duration of initial fast eversion following initial contact, e: duration of the slow re-inversion during stance. Note that all angle values are relative to static standing posture.



by approximately 15°. In late stance, that is, during the push-off phase, the ankle plantarflexes considerably to become plantarflexed by approximately 15–20° at toe-off. During swing phase (not the focus of this paper) the ankle becomes more dorsiflexed again to allow for suitable toe clearance with the substrate (Fig. 2).

Our quantitative analysis shows that, in a similar fashion for both footwear conditions, the ankle is more plantarflexed at initial impact when walking on the artificial substrate (Fig. 4a). Maximal plantarflexion values in early stance do not differ between the four conditions (Fig. 4b). Maximal dorsiflexion in late stance only differs between the conditions on an artificial substrate, with the shod condition involving a less dorsiflexed ankle (Fig. 4c). At toe-off, differences are most pronounced between substrate conditions (but we also observe small differences between footwear conditions). In either footwear condition, walking on the artificial substrate involves a smaller degree of plantarflexion at toe-off (Fig. 4d). In addition, the barefoot condition shows a smaller degree of plantarflexion at toe-off on both substrates.

Ankle kinematics: eversion/inversion

The general pattern for ankle inversion/eversion is the same for all conditions (Fig. 2). At heel strike, the ankle is inverted by approximately 10° (relative to static standing). It then quickly everts to approximately neutral position, where it starts a slow re-inversion peaking at approximately 20° near toe-off.

Our quantitative analysis shows that ankle inversion at initial contact is similar for all four conditions. We only found a difference between barefoot and shod walking on the natural substrate: when barefoot, the ankle lands more inverted, by 1.3°, than when shod (Fig. 5a). After initial contact, the ankle everts to a peak value, which differs only between the shod condition over the sub-

strates and is smaller (more everted) on the natural substrate than on the artificial substrate (Fig. 5b). The duration of this rapid eversion motion is mostly similar between conditions, but we found that it was smaller (by 0.03s) when shod compared to barefoot, on the natural substrate (Fig. 5e). The slow inversion motion during most of stance phase peaks at a similar value for all conditions (Fig. 5c) and takes a similar amount of time (Fig. 5e).

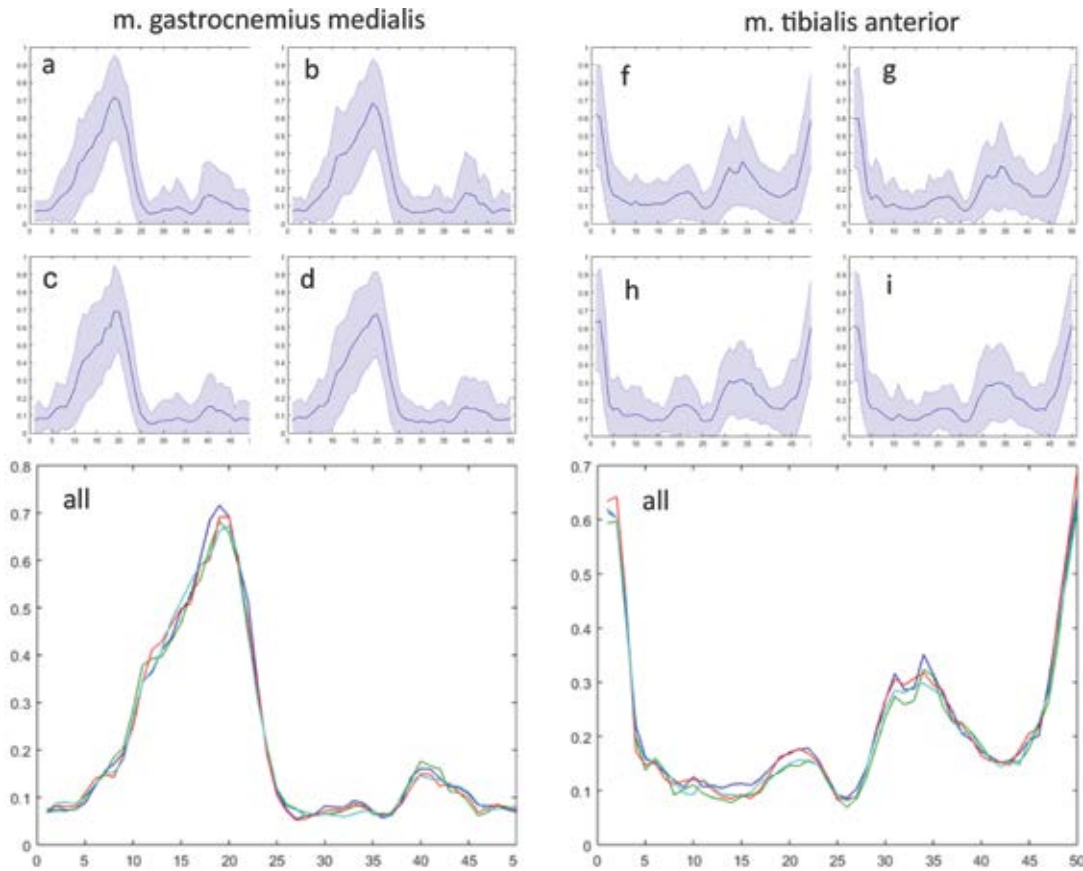
Electromyography

Patterns of sEMG activity are very similar between conditions (Fig. 6). The m. gastrocnemius medialis has one main activity peak, during the push-off phase in mid/late stance, and a smaller peak just prior to touch-down. The m. tibialis anterior shows a high activity around the instant of touch-down, and a smaller peak during swing phase. Both patterns correspond well with those from the literature (e.g. Hof et al., 2002). Total activity of the m. tibialis anterior is lower for barefoot walking than for shod walking. Concentrating on barefoot walking alone, activity is lower on the natural substrate than on the artificial substrate (Fig. 7a). Total activity of the m. gastrocnemius medialis is similar in all conditions and we only found a difference on the natural substrate, where the barefoot condition involves lower muscle activation than the shod condition (Fig. 7b).

Discussion

To the best of our knowledge this is the first report and quantitative analysis of diverse biomechanical data (kinematics, kinetics, muscle activity) of people walking in indigenous footwear and walking barefoot on a natural substrate and on an artificial substrate. The study has highlighted statistically significant differences in impact accelerations, ankle rotations over a larger range,

Figure 6
EMG profiles for the m. gastrocnemius medialis (left) and for the m. tibialis anterior (right). All plots are one stride, from right initial contact to the consecutive right initial contact. The top panels show average curves ± standard deviation for all trials per condition. The bottom graphs show the average curves for all four conditions, where the input data were normalised by dividing values by the peak value observed on the step. Note that shape of the normalised sEMG profiles is very similar between conditions.



and muscle activity of the m. tibialis anterior and the gastrocnemius while walking on different substrates and footwear conditions (that is, barefoot or indigenous).

A limitation of our study is the fact that we measured impact by means of acceleration, and not by force. The use of a forceplate is not suitable for the fieldwork conditions and the type of measurement considered here. First, the hard surface of the forceplate differs substantially from a natural surface and is not suitable for measuring the effect of substrates; second, because of its weight a forceplate is not practical for fieldwork. Furthermore, we note that soil density is not constant but depends on the season. In general, a wet substrate has a lower density, which is consistent with our soil analysis with a penetrometer. The rain season is short, lasting only about two months.

As described above, walking speeds were measured only on the artificial substrate, because obtaining speeds on the natural substrate was difficult for practical reasons. We do not expect, however, that a speed difference (if any) would be significant. The speed difference between footwear conditions is very small (shod: $1.27 \pm 0.1\text{m m/s}$; unshod: $1.30 \pm 0.14\text{ m/s}$). This is consistent with the findings of Price et al. (2014), who found that walking speed of people walking in flip flops in their daily lives (1.31 m.s.) is comparable to barefoot walking. For this reason we did not deal with speed effects in this paper.

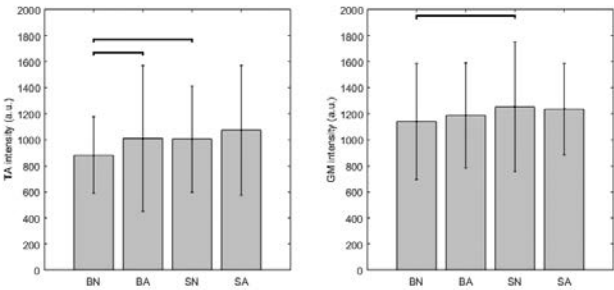
Because of differences in methodology and protocol, the results obtained here cannot easily be compared with that of the other studies cited in this paper. Indeed, only a small number of papers compare barefoot and shod walking, even fewer examine the effect of substrate, and none of the papers cited compares substrates and footwear condition at the same time. We note that the outsole properties were similar for all

subjects. We recognize that the relatively small sample size of this study may limit the generalizability of the results, and future research will include more subjects.

At the end of the introduction we formulated hypotheses that we set out to test. First, based on our findings that for both footwear conditions (that is, shod or unshod) the impact acceleration on the natural substrate is higher than on artificial substrate, we reject the hypothesis that walking on (hard) artificial substrates always involves higher impact accelerations than on (softer) natural substrates. Second, we confirm that the barefoot condition yields higher impacts than the shod condition, but the differences are small and only significant for the artificial substrate. Third, our hypothesis that the artificial substrate involves faster ankle rotations over a larger range (than natural substrate) regardless of footwear condition is confirmed. We note that the duration of rapid eversion motion is mostly similar between conditions and that (at least on the natural substrate considered (Fig. 5e) it was smaller (by 0.03s) for shod than barefoot.

Previous biomechanical studies investigated the implications of walking in flip-flops compared to barefoot and/or closed toe footwear (Zhang et al., 2013; Chard et al., 2013; Schroyer and Weimar, 2010). All shoes, even the open-toe footwear, yield different ankle kinematics compared to barefoot. Consistent with the findings of Zhang (2013) the barefoot condition yields a shorter stance duration in comparison to walking with conventional sneakers. The findings of Schroyer and Weimar (2010) revealed that compared with sneakers flip-flops resulted in a shorter stride length and a shorter stance time. Our findings that stance duration is shorter barefoot than shod on the natural substrate, and that stride duration is shorter barefoot than shod on an artificial substrate, is consistent with the hypothesis that “the more minimal the shoe, the shorter the strides and stance”.

Figure 7
Results for total EMG during a stride. From left to right a: m. tibialis anterior, b: m. gastrocnemius medialis (a.u., arbitrary units)



In addition, the barefoot condition shows a smaller degree of plantarflexion at toe-off on both substrates. This is consistent with the findings of Schroyer and Weimar (2010) who revealed that compared with sneakers flip-flops resulted in a larger ankle angle/dorsiflexion at the beginning of the double support phase. Keenan (2011) identified potentially clinically relevant changes in joint moments that occur with the shod condition. The most likely causative factor was the increased stride length and its associated changes in ground reaction forces. The study of Chard (2013) shows that thongs resulted in increased ankle dorsiflexion during contact both for walking and jogging. To explain the increased ankle dorsiflexion during the contact phase while walking with flip flops, Chard et al. (2013) refer to a mechanism to retain the thong. While these compensations exist, the overall findings suggest that foot motion whilst wearing thongs may be more replicable of barefoot motion than originally thought.

The footwear condition does not show a significant difference on the angle of ankle dorsiflexion. The design of the Kolhapuri footwear features an instep band over the arch which holds the foot close to the outsole. This design reflects the barefoot walking kinematics better than the design of the flip flops. On the one hand ankle kinematics shows adjustments in foot strike on different substrates (as in running). Our quantitative analysis shows that, in a similar fashion for both footwear conditions, the ankle is more plantarflexed at initial impact when walking on the artificial substrate

(Fig. 4a), regardless of whether the person is shod or unshod. This can be related to a more pronounced heel strike and corresponds with the findings of De Wit et al. (2000) who studied the heel strike during running. We also note that the natural soil our subjects walked on is hard and comparable to a layer of buffalo leather (for details see Willems, 2013). On the other hand, literature reports that leg stiffness adjustments are accompa-

nied by kinematic and kinetic adjustments (Ferris, Louie, & Farley, 1998). Runners quickly adjust their leg stiffness on their first step when they encounter a new surface such as the transition from a soft to hard surface (Ferris, Liang, & Farley, 1999). Tillman et al. (2002) found no significant differences in forces on the plantar side of the foot among the different running surfaces (asphalt, concrete, grass, and a synthetic track).

Muscle activity of the tibialis anterior

Our results show –as expected– a lower muscular activation of the m. tibialis anterior on a natural substrate. Total activity of the m. tibialis anterior is lower for barefoot walking than for shod walking. In the same line Kung (2015) found an increase in the dorsiflexor impulse throughout the stance phase during shod walking, compared to barefoot walking.

Conclusions and future work

The current study revealed that (for the footwear considered) gait biomechanics between footwear conditions are of the same magnitude or smaller than the differences between the two substrates. On the one hand, this suggests that substrate has a greater effect on the measured variables than footwear, but the limited number of subjects and types of footwear considered in this study prevents us from making a more general statement. On the other hand, from the subtle differences between the conditions shod and unshod we conclude that the Kolhapuri footwear is very similar to barefoot walking. This type of indigenous footwear ‘mimics’ barefoot gait offering protection and might therefore be considered *minimal*. Future research will compare them to modern, western “minimal footwear”.

Further investigation on plantar pressures and on foot and ankle kinematics in walking is needed. With regard to plantar pressure distributions, reference data are available for barefoot walking (Bennett and Duplock 1993; Blanc et al., 1999; Bryant et al. 2000; Hennig and Rosenbaum, 1991; Hennig et al. 1994) and for barefoot jogging (De Cock et al., 2005).

The modern world’s social demands do not allow us to live barefoot, and foot protection and fashion will continue to drive the need for footwear. This research shows that the role of the ancient can inspire footwear designers and that continual use of high quality data collection methods can help both the footwear artisans and the footwear industry.

Acknowledgements

Our gratitude goes to the artisans and the management of Toehold Artisans Collaborative for their enthousiast participation and extensive support throughout the project. A special thanks goes to Mrs. Madhura Chattrapathy and Mr. Raghu Kerayil of Toehold for facilitating all logistics and communication between the artisan community and us.

This research was financially supported by the School of Arts KASK, University College Ghent, Belgium, as part of the PhD research project ‘Future Footwear’.

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BIOMECHANICS



BIOMECHANICS

Plantar pressures in two types of indigenous footwear, minimal shoes, and western shoes, compared to barefoot walking

Catherine Willems¹
Russell Savage²
Gaetane Stassijns³
Dirk De Clercq⁴
Kristiaan D’Août^{2,5}

¹ Department of Design, University College Ghent, Belgium

² Department of Musculoskeletal Biology, Institute of Ageing and Chronic Disease, University of Liverpool, UK

³ Department of Physical Medicine, University Hospital Antwerp, Belgium

⁴ Department of Movement and Sport Sciences, Ghent University, Belgium

⁵ Department of Biology, University of Antwerp, Belgium

Abstract

Humans evolved as barefoot walkers, and only started to use footwear recently in evolutionary history. Therefore, it can be questioned what the effect is of footwear on gait. In this paper, we assess plantar pressure distributions (peak pressures and pressure-time integrals) in three populations: South Indians wearing indigenous footwear (“Kolhapuri”), Northern Scandinavians wearing a very different type of indigenous footwear (“Nuvttohat”), and Western Europeans wearing a commercial “minimal shoe” as well as their own daily footwear. Within each population, data were compared to barefoot walking. Significant differences were found between all footwear conditions and barefoot walking. However, all indigenous as well as the minimal footwear conditions resemble barefoot walking closer than conventional Western footwear. Based on plantar pressure recordings, we conclude that Kolhapuri footwear, Nuvttohat footwear, and commercial minimal shoes, can all be considered “minimal footwear”, with some differences to barefoot walking. Further research should focus on walking kinematics and on temporal aspects of foot unroll with different types of footwear.

Introduction

Most people, especially adults, wear some form of footwear on a daily basis. Not surprisingly, a large body of work exists on biomechanical effects of footwear. These studies have focused predominantly on functional sports shoes, for instance for running (e.g. for injury prevention and performance enhancement, see Nigg, 2010) and on therapeutic footwear and/or orthotics for specific patient groups (e.g. neuropathic diabetic patients, or people with flatfeet, pes planus). Surprisingly, relatively little work has been done on daily walking, even though it is often suggested that daily footwear might have a large effect on long-term biomechanical health. Specifically high heeled shoes are problematic (Coughlin, 1995; Frey, 2000) and even moderate heels have been suggested to have a negative effect on knee osteoarthritis (Kerrigan et al., 2005). Hallux valgus (bunions), one of the main foot problems especially for women (Easley & Trnka, 2007, for a review, see Nix et al., 2012) has been suggested to be strongly influenced by the adoption of stiff, heeled footwear (Mafart, 2007).

A large variety of footwear is used on a daily basis, ranging from thin-soled ballerina-style footwear, to rigid boots, to high heels. Most types of habitually worn shoes do not claim to benefit health, and for some it has been clearly demonstrated that they actually impede health (e.g. high heeled shoes). For those shoes that have not been shown to impede health (e.g. many daily worn shoes) it is unclear what their effect is. Interestingly, what we consider “daily” or “conventional” footwear is a fairly recent and mostly Western invention. The oldest footwear found is approximately 8300 years old, a sandal made from plant fibre (Kuttruff et al., 1998). Archaeological findings show that also ancient Egyptians (e.g. Sesana, 2005; Veldmeijer, 2012), ancient Romans (Van Driel-Murray, 2001; Allison, 2006;

Cleland et al., 2007), and people in the Middle Ages used footwear that could be considered fairly “minimal” to current standards, with heels probably invented in the 16th century (Carlson, 1999). Shoes seemed to be non-constricting, there was no rigid heel cup, no arch support, little cushioning and no elevated heel; features with potential biomechanical effects that are omnipresent in what we will call “conventional” footwear for the purpose of this study. We will use the term “minimal” footwear for footwear that generally can be considered to promote kinematics and kinetics (forces and pressures) akin to barefoot walking. Such shoes typically have little to no cushioning, no rigid heel cup, no arch support and very low to zero heel to toe offset (the difference in sole height between the heel and the forefoot).

Our recent adoption of conventional footwear in the last few centuries is in stark contrast with our anatomical, evolutionary development. Indeed, the oldest anatomically modern humans, *Homo sapiens*, were dated to approximately 200 000 years ago (McDougall et al., 2005) and hallmark characteristics of the modern human foot may have existed for several millions of years (Bennett et al., 2009). Since humans have been successful for such long periods, it can be questioned why we would need footwear with biomechanical effects (of course, footwear can serve other than biomechanical functions, e.g. protection from the cold or from sharp objects). Selection is likely to have acted very strongly on the human foot and on locomotor anatomy in general, so why would we need to interfere with their function for normal, daily locomotion? The foot is the only part of the body that is often judged to need biomechanical assistance. For instance, we do not use rigid clothing to help support the weight of the head, or gloves with biomechanical function to carry objects. In the rare cases where we do support parts of the body, e.g. when applying plaster

casts to help fracture healing after trauma, muscle atrophy is observed (Appell, 1990). Experimental work to address these issues is impossible for obvious ethical reasons. However, the opposite approach can be used, and indeed it has been shown that athletes training in “minimal” footwear gain foot muscle strength compared to those using conventional trainers (Goldmann et al., 2013; Miller et al., 2014).

Whereas barefoot or minimally shod daily locomotion makes a lot of sense from a paleoanthropological point of view, this does not guarantee that any type of footwear with a biomechanical function is necessarily undesirable even in healthy people (in several patient groups, e.g. diabetic patients, the benefits of footwear are clear). Indeed, the sharp post-industrial increase in health and lifespan can be largely attributed to “unnatural” interventions (in the sense that we evolved to modern humans without them). Ultimately, we will need to answer the question which type of footwear stimulates long-term biomechanical health, starting in childhood and continuing to the elderly, where specific gait-related issues may arise (e.g. instability, osteoarthritis and osteoporosis).

Interestingly, even to date, several populations habitually use footwear that cannot be categorised as “conventional” but indigenous and as this footwear has been in use for centuries, the question arises if such footwear might be considered minimal. Therefore, in this study we set out to explore some of the biomechanical properties of walking in such footwear and we will compare to a modern, commercially available type of minimal footwear, and to conventional footwear. Moreover, every shod condition will be compared within-subject to barefoot walking.

The first type of indigenous footwear is the South India “Kolhapuri” footwear, a type of

sandal that fits tightly onto the foot by having an instep strap, and that has a thin sole made of vegetally tanned buffalo leather, typically with a very thin heel offset created by an extra layer of buffalo leather. This type of footwear is used in a very hot and usually humid climate (Figure 1 C). The second type of indigenous footwear is the Northern Scandinavian “Nuvttohat” or reindeer boot, as traditionally worn by the Saami people. This boot is made entirely from vegetally tanned reindeer hide and used in an extremely cold climate. Grass is used for insulation (and may provide some cushioning), but these boots do not possess any of the features of conventional footwear (Figure 1 D). We refer to Chapter 6 of this thesis for a more elaborate description of the indigenous footwear.

As a first biomechanical approach, we will use plantar pressure recordings with a pressure plate to ask whether the local distribution of pressures under the foot differs (and if so, how) between indigenously or minimally shod walking, and conventionally shod as well as barefoot walking in healthy subjects. Plantar pressure recordings have been used extensively to assess several types of footwear. Most studies have used pressure sensitive insoles (e.g. Burnfield et al., 2004; Erdemir et al., 2005; Carl & Barrett, 2008; Martínez-Nova et al., 2008; Lange et al., 2009; Molloy et al., 2009; Sacco et al., 2009; Price et al., 2013; Forghany et al., 2014) and there has been a strong focus on plantar pressure studies in diabetic patients with peripheral neuropathy, as there is a close relationship between high plantar pressure and ulcer formation (e.g. Stess et al., 1997; Frykberg et al., 1998; Armstrong et al., 2004; Pataky et al., 2005). The vast majority of studies have focused on running (e.g. De Wit et al., 2000; Paquette et al., 2013) or on patient groups, and either studied barefoot walking (typically on a force plate) or shod walking (typically with pressure-sensitive insoles).

To the best of our knowledge, there are no studies on walking, comparing barefoot and shod conditions using pressures plates (but see Dixon & McNally, 2008 for a study on running).

Since any shoe likely provides some (even if minimal) amount of cushioning or pressure redistribution, we hypothesise that peak pressures in any shod condition will be lower than in barefoot walking. We also expect the temporal pattern of foot unroll in indigenous or minimal footwear to be more similar to that of barefoot walking, than is the case for conventionally shod walking.

Methods

Subjects

Three populations were studied. The South Indian population (n=36) consisted of adult males and females from in and around the rural village of Athani in the state of Karnataka. The Scandinavian population (n=36) consisted of male and female adults from in and around Inari, Northern Finland, of which a large fraction had a Saami background. The Western population (n=30) consisted of Caucasian male and females, mostly from Belgium. Subjects with current or recent foot or lower limb injuries were excluded. (Please see Table 1 for details.)

Materials

An RSScan Footscan USB (0.5m version) with Footscan USB 7 Gait software, running on a laptop PC, was used for all recordings. Calibration was regularly performed using the manufacturer’s guidelines. Data were recorded at a temporal resolution of 300 fps and a spatial resolution of 7.62 mm along the long axis (walking direction) and 5.08 mm along the short axis left-right) of the plate. In each of three setups, the plate was installed indoors, on a flat and hard surface (see Figure 1 A–B for examples).

In addition to the pressure plate, we record-

ed kinematics (not reported here) using a laterally positioned overview camera and two perpendicular cameras zoomed in on the foot.

Protocol

All subjects signed informed consent (ap-proved by the University of Antwerp Ethics Committee). We collected basic morphomet-rics (stature, mass, leg length as measured from the trochanter major to the ground, navicular height) as well as mechanical properties of the footwear in the Indian sub-study (not reported here).

Subjects were instructed to walk barefoot at preferred speed over the pressure plate, with at least three steps before and after the plate. The effect of plate targeting was minimised by asking subjects to focus on a distant, eye-level mark. Several trials were recorded until we had three successful recordings for both the left and right foot. A recording was considered successful if there was no obvious acceleration or deceleration, any other manoeuver (e.g. turning) and con-sisted of normal, comfortable walking. The procedure was repeated for walking with Kolhapuri footwear (in the Indian sub-study), Nuvttohat footwear (in the Scan-dinavian sub-study) and with commercial minimal footwear (Vivobarefoot “The One”) as well as the subject’s own daily footwear (in the Western sub-study) (Figure 1 C–E). A total of 728 trials were used for this analysis.

Analysis

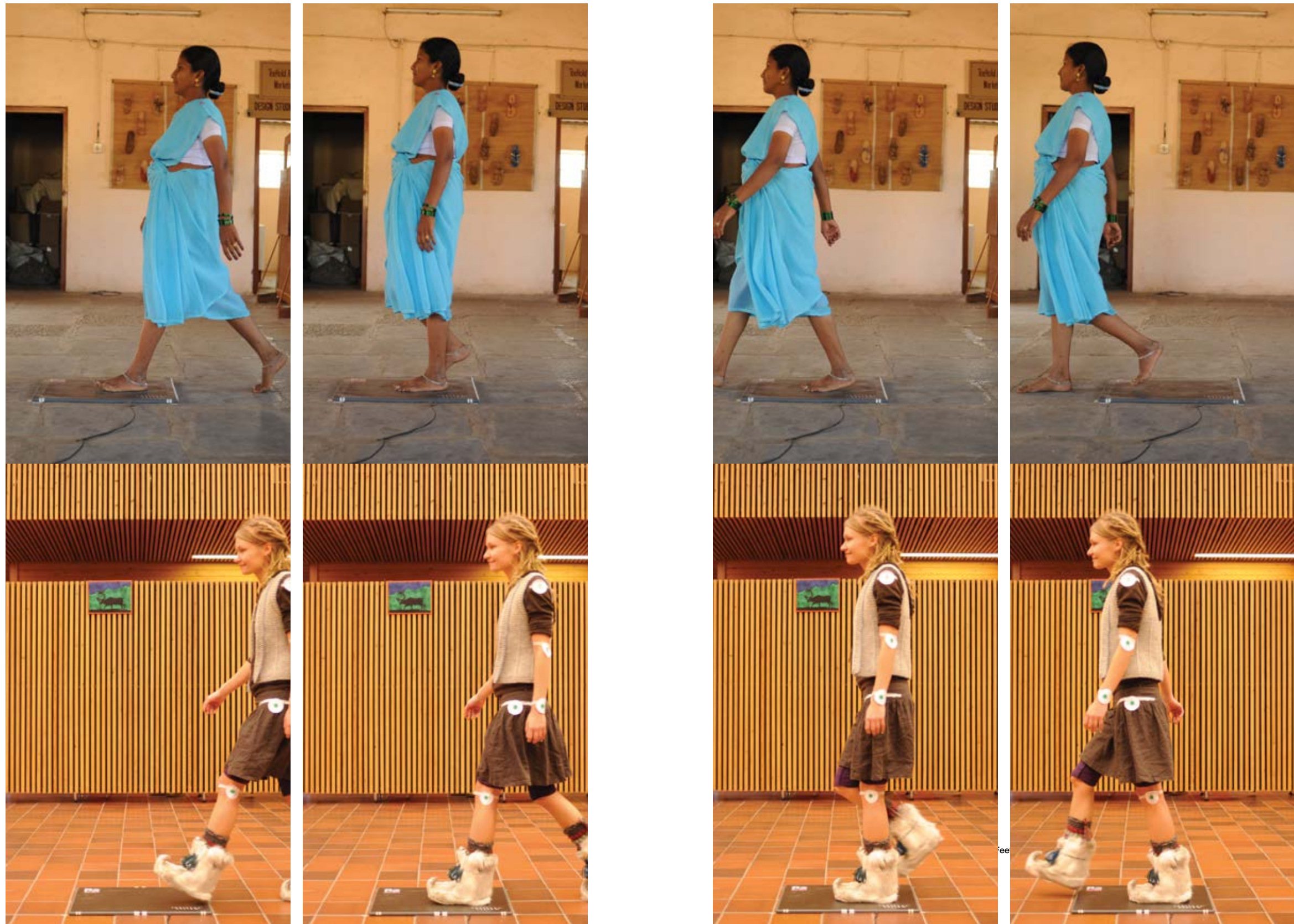
Preparation of the pressure records

The numerical data of the full pressure time series (i.e. 3D data: pressure (kPa) of every cell over time (s)) were exported from the acquisition software to ASCII text files and imported into MatLab (versions used: 2013a to 2015a), where all further analysis was performed.

Table 1
Overview of subject data

	Finland <i>n</i> =36		India <i>n</i> =36		Belgium <i>n</i> =30	
	Male	Female	Male	Female	Male	Female
	(<i>n</i> =14)	(<i>n</i> =22)	(<i>n</i> =23)	(<i>n</i> =13)	(<i>n</i> =14)	(<i>n</i> =16)
Age(years/mean)	52	46	41,4	39,6	39	38
Mass (kg/mean)	83,9	65	58,7	55,4	84	59
Height (m/mean)	1,74	1,60	1,63	1,49	1,81	1,68
BMI (mean)	27,6	25,3	22	24,8	25,5	20,9

Figure 1A & 1B
 Examples of the pressure plate setups, A, A South Indian subject walking barefoot.
 B, A Scandinavian subject walking shod, using her indigenous 'nuvttohat' footwear



In a first step, the pressure images were resampled from the non-square pressure cells into square (5mm x 5mm) pixels, and right feet were mirrored, assuming population-level symmetry (see Figure 2).

From the resampled data, we generated footprint plots in two ways. Firstly, we determined peak pressure for each pixel over the course of contact. In this case, the pixels with the highest values are those encountering the highest peak pressure over a step, however brief. The resulting 2D peak pressure plots do not contain timing information. Secondly, we calculated pressure-time integrals for each pixel, so that the values per pixel result from both pressure and timing data. In this case, the pixels with the highest values have the highest contribution to the generation of vertical impulse, which can be achieved in different ways, e.g. by a moderate pressure applied over a long time, or by a very high pressure over a shorter time. The pressure-time integral plots are 2D but implicitly contain timing data.

Both of these approaches are useful; the first by highlighting which parts of the foot receive the absolute highest loads, the second one by showing which parts of the foot contribute most to the vertical impulse, which needs to be generated in order to keep the body upright (see Figure 3 for an example). In this paper, we mainly focus on peak pressures, which are strongly correlated with pressure-time integrals (and mean pressures, see Keijsers et al., 2010) for the statistical analysis and we performed a preliminary analysis on the timing of foot unroll in the Western sub-study but we will first describe the analysis of the 2D plots.

Normalisation of pressure records

Pressure is defined as perpendicular force divided by the area over which the force acts; therefore, with a horizontally installed plate, integrating all pressures (i.e. of an entire foot) over the entire foot area yields vertical

ground reaction force, F_z . The latter is composed of gravity, and a second force which will accelerate the body with mass m :

$$F_z = m \cdot g + m \cdot a_z$$

If the body has no overall vertical displacement over a stride (or any sufficiently long stretch of time), i.e. its vertical displacement averages zero, it will also have an average vertical velocity, and acceleration a_z , of zero. In this case, the average F_z over a full stride must be identical to body weight ($m \cdot g$) for both feet, or half body weight for a single footfall (in a symmetrically walking subject). In other words, the average F_z over a stride is constant and the impulse (the force-time integral) over a stride is constant.

We have used this idea to normalise pressure data. First, we calculated the integrated pressures for every single image, then averaged these values (including the zero values during swing phase), and scaled them to body weight. We then used this factor to recalculate the individual pressures for any pixel. This approach will yield pressure records that are comparable between different pressure plates, and also between subjects, in which a value of one (see Figures 6-8) corresponds to average pressure.

Body mass in human adults scales allometrically to stature squared; this is known as the Body Mass Index (Quetelet, 1835; Heymsfield et al., 2007). Feet however, do scale close isometrically in adult humans, with foot length being approximately about 15% of stature (Atamturk & Duyar, 2008). The result is that, assuming the same BMI, a taller person will have a larger mass but also a larger foot area and since both scale similarly -to stature squared- they will cancel each other out. Therefore, on theoretical (scaling) grounds, we do not expect differences in absolute pressure values between subjects of different stature, provided similar BMI.

Figure 1C-E
Footwear types.
C, Kolhapuri footwear; D, Nuvttohat footwear; E, Commercial minimal footwear.



Differences exist between our populations (see Table 1), but since we will adopt a within-population approach, this will not bias results.

Linear image registration and analysis

Biological data are variable; no two pressure records are the same (see Figure 4). In order to compare pressure records statistically, they need to be registered so that they show maximal overlap, regardless of the orientation of the foot on the plate, or of the absolute size of the foot.

The six records (either peak pressure or pressure-time integrals) per category (subject and condition) were registered within the category (see Pataky et al., 2008b) and averaged. Consequently, the shod images were registered to the barefoot ones and averaged, allowing for a direct comparison between conditions. Consequently, records were registered between subjects. Figure 5 illustrates the results of this process for the Indian subjects. The registered images were subject to statistical pSPM analysis – pedobarographic Statistical Parametric Mapping (Pataky, 2008; Pataky & Goulermas, 2008). We applied this method to the barefoot and indigenously or minimally shod data. Conventional (daily) footwear in the Western data set was not standardised and therefore very variable, ranging from thin-soled flat shoes, to sneakers, to relatively stiff, heeled shoes. Therefore, we deemed it inappropriate to average these data (they are very much influenced by the shape of the shoe), and rather analyse them strictly within subjects. Figure 9 is an example of one subject wearing daily footwear, Kolhapuri footwear and commercial minimal footwear.

Foot unroll analysis

For a subset of 13 Western subjects, we performed a preliminary analysis in order to investigate if timing of the foot unroll, complementary to pressure and pressure-time integral magnitudes, might be

able to distinguish between footwear conditions. We quantified foot unroll timing as the displacement of the Centre of Pressure (CoP) from heel to toes along the long axis of the registered pressure records. We did this for the barefoot, the minimally shod, and the conventionally shod conditions. CoP coordinates were calculated, frame by frame, as the weighted average of pressure along the long axis. Raw displacements were normalised spatially by resampling them from 0% (corresponding to the location of the CoP at heel strike) to 100% (corresponding to the location of the CoP at toe-off). Temporal normalisation was done by resampling from 0% (corresponding to the time of initial contact) to 100% (corresponding to the time of toe-off).

Results

Indian sample – Kolhapuri footwear

Comparing the full data set for barefoot peak pressure recordings with that for shod (Kolhapuri) walking shows a good correspondence (Figure 6 A, B). Indeed, even in the shod condition, the heel, hallux, and metatarsal head region can be easily identified. The locations of maximal pressure seem to correspond well, except in the metatarsal region.

The shod print shows a zone of moderate pressure distally to the toes due to the presence of a sole that extends beyond the toes. Despite the good visual correspondence, the analysis found significant differences between the two conditions. The shod conditions showed significantly higher pressures, as can be seen from the comparison plot (Figure 6 C), at the distal end and generally at the periphery of the print. This can be explained by the shoe being slightly larger than the foot sole, thereby exerting pressure where the barefoot does not. These differences, although significant, are of less biological relevance. When comparing the central area of the comparison plots (Figure

6 C, D), i.e. under the foot area itself, significant differences can be observed at different sites. Barefoot walking involves higher peak pressures under the hallux, the medial metatarsal region (esp. metatarsal II head), the metatarsal V head, the midfoot and the lateral heel. Shod walking involves higher pressures at the lateral toes, the lateral metatarsal (III-IV) region, and the medial heel.

Scandinavian sample- reindeer fur boots

When comparing the distribution of peak pressures (Figure 7 A, B), it is clear that fine spatial details (e.g. individual toes) cannot be seen in the shod print. However, the overall shape and pressure distribution pattern is qualitatively preserved. pSPM analysis (Figure 7 C, D) shows significant differences between conditions. When indigenously shod, the Scandinavian subjects show a lower pressure under the hallux and the lateral toes, under metatarsal V, and under the heel (blue colours in Figure 7). They show increased pressure between the metatarsal heads and the distal phalanges and in the entire midfoot region (red to white colours); these are regions that make very little ground contact when barefoot.

Western sample –minimal and conventional footwear

When comparing the average plots for minimally shod to barefoot walking, we observe close visual correspondence between these conditions (Figure 8 A, B), with most anatomical zones (but not separate toes) recognisable even in the shod condition, and with good correspondence of the locations of maximal pressure. Overall, the shod condition has lower peak pressures, over a larger area.

Locations of maximal pressure are similar: the heel, the hallux, and metatarsal heads II-III, but in all three cases, barefoot pressures are significantly higher than shod pressures (Figure 8 C, D). As in the Indian sample (and for similar reasons) the bare-

foot condition involves higher pressures at the lateral metatarsal (V) region and the shod condition involves higher pressures at the proximal heel and the distal toe region. However, the minimal shoes involve higher midfoot pressures than in the barefoot control trials.

We did not involve the conventionally shod trials in this population –level quantitative analysis, because of the large variation in footwear types, but within-subject comparisons for all subjects are available. An example of average pressure plots for a single subject is given in Figure 9. The normalised trajectory of the Centre of Pressure (CoP) along the long axis of the foot was compared for all data available (Figure 10). It can be seen that the CoP displacement along the long axis (representing the heel-to-toe foot unroll pattern) for the minimal footwear is closer to the barefoot condition than is the conventionally shod condition.

Discussion

Shod versus barefoot walking: within-group comparisons

Visual inspection of average peak pressure plots (Figures 6-8 A, B) reveals a close match between pressure distributions when barefoot, and when using indigenous footwear as well as commercial “minimal” footwear. pSPM has shown to be a sensitive method, however, that showed significant differences between shod and barefoot walking in all three populations.

We hypothesised that, since any shoe likely provides some degree of cushioning, peak pressures in any shod condition would be lower than in barefoot walking. This appears to be generally the case in all three populations for the anatomical zones that have the highest pressure: the heel, metatarsal (esp. II-III) heads, and the hallux. In contrast, zones that receive low pressures when barefoot, typically show higher pressured

when shod. An exception is the midfoot in the India sample, which shows a lower peak pressure when shod. This can probably be explained by the presence of a very low heel in the indigenous shoes, lifting the midfoot off the substrate in many cases. The combined effect of the general reduction in pressure of high-pressure zones and increased pressure in low-pressure zones is that, as expected, pressures are more equally distributed over a larger area when shod, at least at the level of the shoe-substrate interface.

In the case of the Scandinavian ‘nuvttohat’ footwear, it should be mentioned that they perform best on snow and ice (see physical tests done on the reindeer hide in chapter 6 of this thesis), and that this footwear is traditionally used without a sock, but with a padding of ‘kinkaheina’ grass. We collected data on a hard surface and thus the pressures experienced when walking on snow would probably be even lower than on our pressure plate, or on ice.

Interestingly, the subtle but significant pattern of more uniform peak pressures, seen in indigenously or minimally shod conditions, bears resemblance to a similar pattern of more uniform peak pressures in habitually barefoot South Indians when compared to habitually shod (but barefoot walking in the experiments) peers (D’Août et al., 2009). It could be questioned whether there might be a mechanical explanation for this similarity, i.e. do habitual barefoot walkers have a thicker foot sole functioning in a similar fashion to the very thin leather soles seen in our indigenous footwear, or to the thin rubber sole of commercial minimal shoes?

It should be stressed that plantar pressure recordings, while providing crucial information on the interface between the walking humans and their mechanical environment, do not provide a full picture of the complexity of walking, and differences between

shod and barefoot walking have been well established by kinematics and kinetics (e.g. a variety of Western footwear, Zhang et al., 2013; flip-flops, Chard et al., 2012; 2013; indigenous footwear, Willems et al., In Prep)

Roll-off timing

Our second hypothesis was that the temporal patterns of foot unroll in indigenous or minimal footwear would be more similar to that of barefoot walking, than is the case for conventionally shod walking. Temporal analysis of the Western sample, comparing barefoot with minimally and conventionally shod conditions, suggests that this is indeed the case (Figure 10) and conventional shoes involve a faster CoP displacement in early stance, presumably caused by the increased leverage of the shoe’s heel. More research, specifically into alternative approaches to normalisation of the data, and statistical analysis using vector field statistics (Pataky et al., 2014) is needed.

Barefoot pressure distribution between populations

Because populations differ, and the subject of this paper is to single out the effects of footwear on pressure distributions within populations, we have considered them as three individual cases. It is, however, also interesting to compare the barefoot (and therefore comparable) pressure distributions between populations. As can be seen from Figures 6 and 8, peak pressures never reach the same maxima in Indian or in Scandinavian subjects as in Western subjects (please note the different scale bar in Figures 6–8 A). This corresponds with previous findings, in which not only habitually unshod, but also habitually shod South Indians had a more uniform pressure distribution than a Western sample (D’Août et al., 2009).

Methodological challenges

The Indian and Scandinavian data for this study were collected in rural settings, by bringing in equipment and setting up a

Figure 2
Example illustrating the temporal roll-off in a barefoot walking South Indian male. The full trial consists of 181 frames (0.603s) and the plots show the frames corresponding with 5% intervals, in which 0% corresponds to heel strike and 100% corresponds to toe-off (cooler colours, relatively low pressure, warmer colours, high pressure).

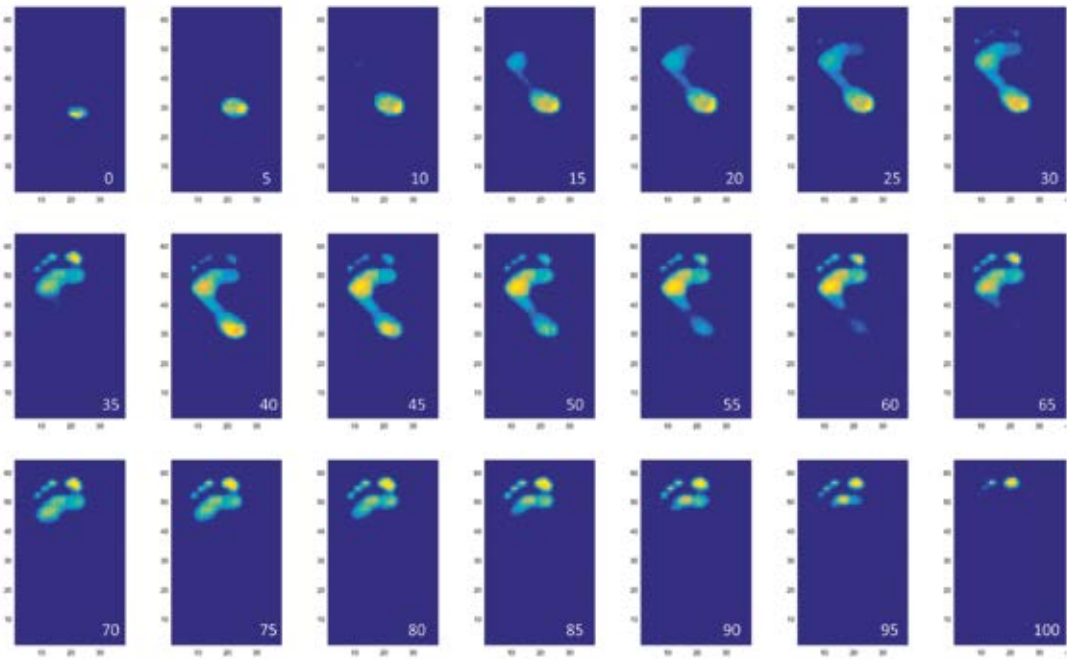


Figure 3
Example of a peak pressure plot (A) and a pressure-time integral plot (B) for the same trial as in Figure 2. Note that there are differences between these plots; in this particular and random example, pressures peak in the heel and the central to medial forefoot, whereas the pressure-time integral shows that the lateral forefoot overall contributes significantly to the generation of the vertical impulse, more so than the heel region (arbitrary units, warmer colours are higher values).

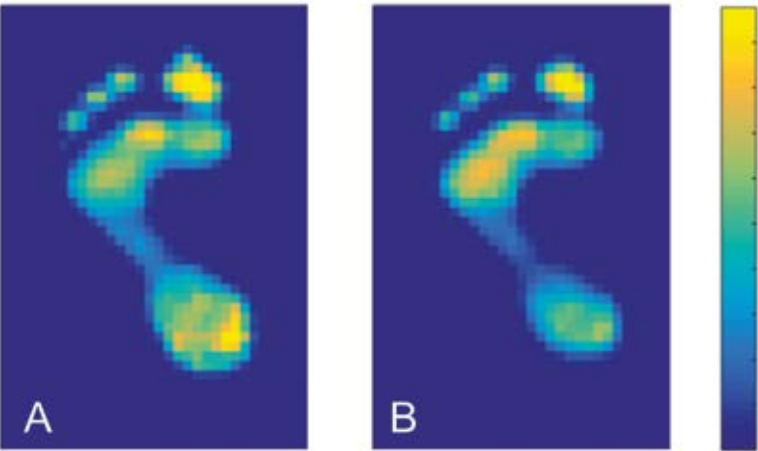


Figure 4
 Pressure-time integrals of six barefoot (A-F) and six indigenously shod (G-L) trials of a single subject. Please note that plots D-F and J-L are mirrored right feet (scale: 100% corresponds to the maximum value over the entire stride).

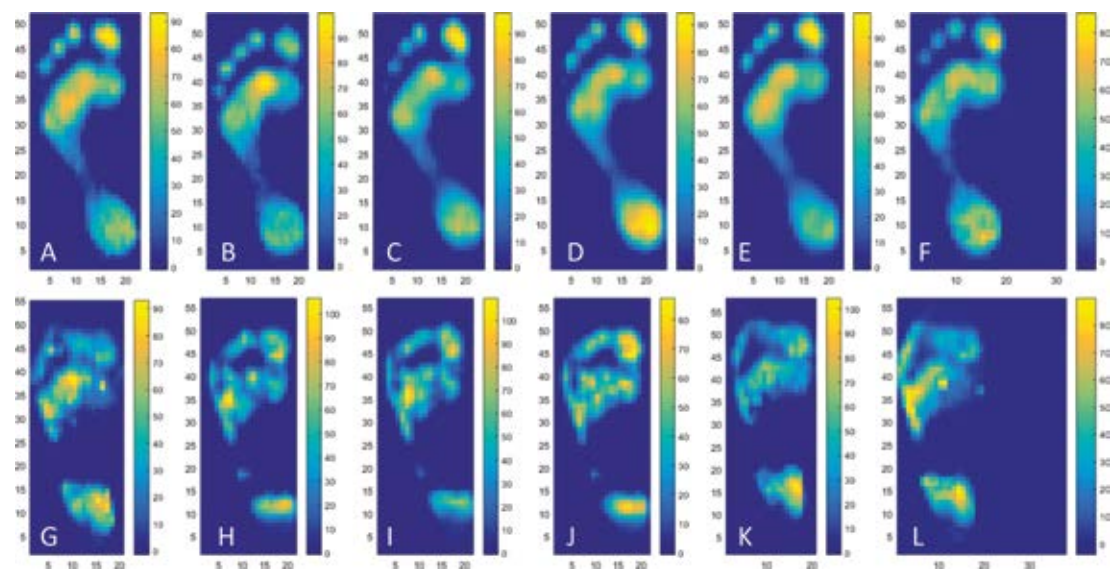


Figure 5
 Image registration for peak pressures (top row) and pressure-time integrals (bottom row). The left figures show the shod trials (registered to each other), the middle figures show the barefoot trials (registered to each other) and the right figures show the registration of the shod trials (dashed background) to the barefoot trials. Note that the shod figures are larger, because the footwear extends beyond the foot, but that there is good correspondence between anatomical sites (e.g. heel, hallux, metatarsal heads; arbitrary units).

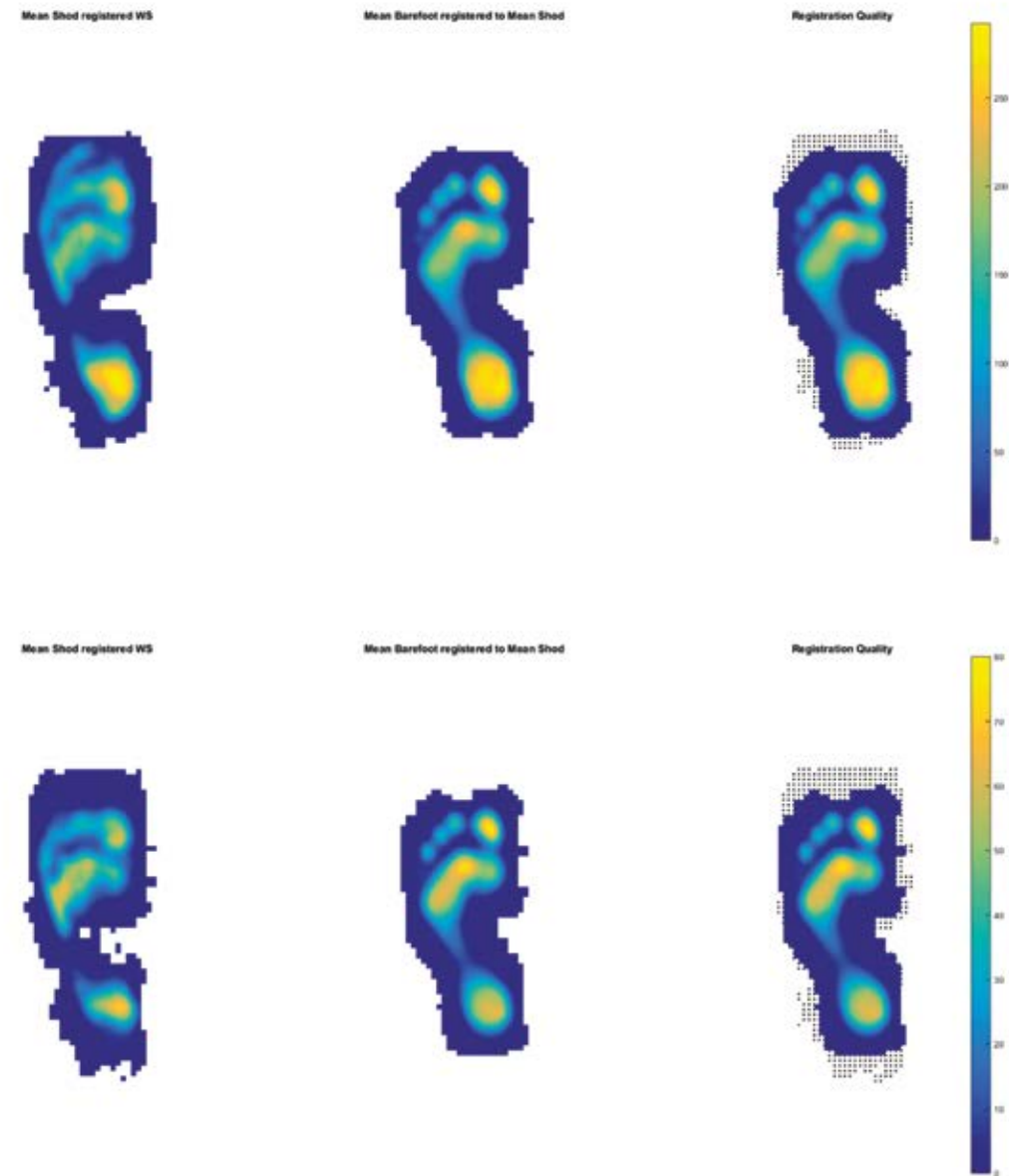


Figure 6
 Comparison of peak pressures across the entire Indian sample.
 A, average barefoot peak pressure; B: average shod (Kolhapuri) peak pressures.
 Colours reflect pressure values relative to the entire-stride average across the entire plate contact. C, raw t values of the statistical inference; D, p values for zones exceeding a cut-off value of $t = 5$. Colours reflect t values. In plots C and D, cooler colours (blue) correspond to pixels where the barefoot pressure is higher, warmer colours (red-yellow) correspond to pixels where the shod pressure is higher.

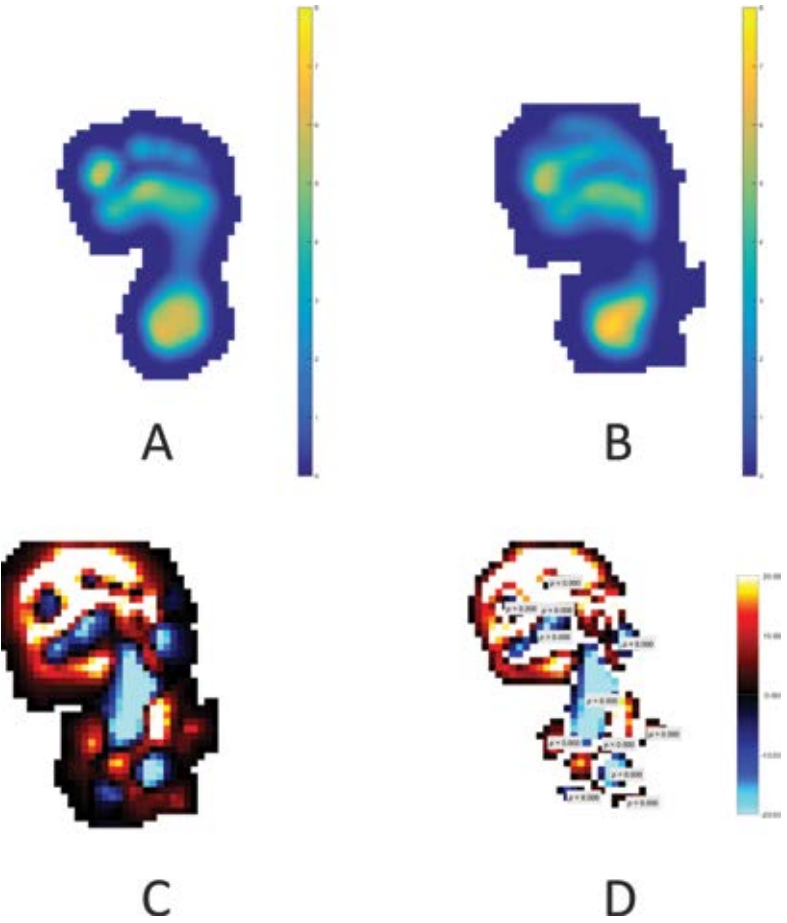


Figure 7
 Comparison of peak pressures across the entire Scandinavian sample.
 A, average barefoot peak pressure; B: average shod (Nuvttohat) peak pressures. Colours reflect pressure values relative to the entire-stride average across the entire plate contact. C, raw t values of the statistical inference; D, p values for zones exceeding a cut-off value of $t = 5$. Colours reflect t values. In plots C and D, cooler colours (blue) correspond to pixels where the barefoot pressure is higher, warmer colours (red-yellow) correspond to pixels where the shod pressure is higher.

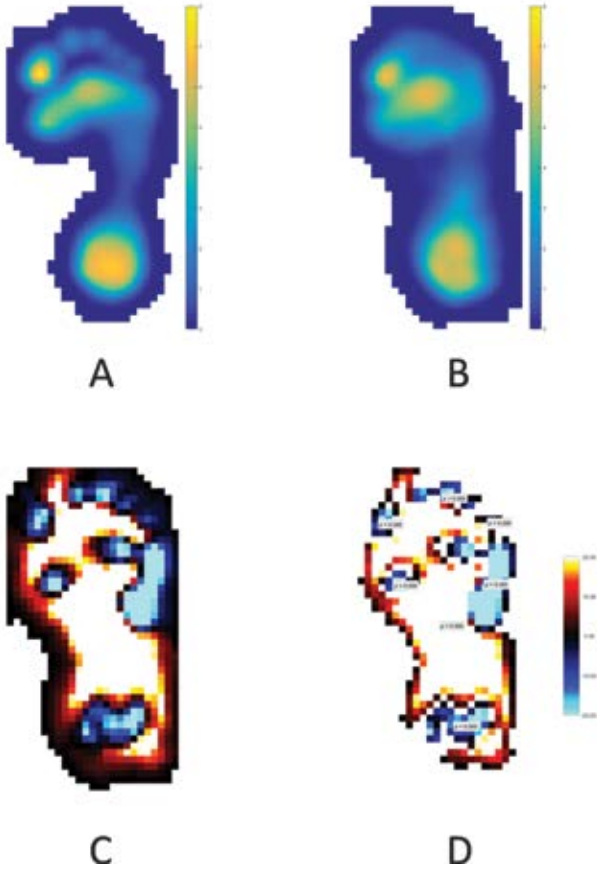


Figure 8
 Comparison of peak pressures across the entire Western sample.
 A, average barefoot peak pressure; B: average shod (commercial minimal footwear) peak pressures. Colours reflect pressure values relative to the entire-stride average across the entire plate contact.
 C, raw t values of the statistical inference; D, p values for zones exceeding a cut-off value of $t = 5$. Colours reflect t values. In plots C and D, cooler colours (blue) correspond to pixels where the barefoot pressure is higher, warmer colours (red-yellow) correspond to pixels where the shod pressure is higher.

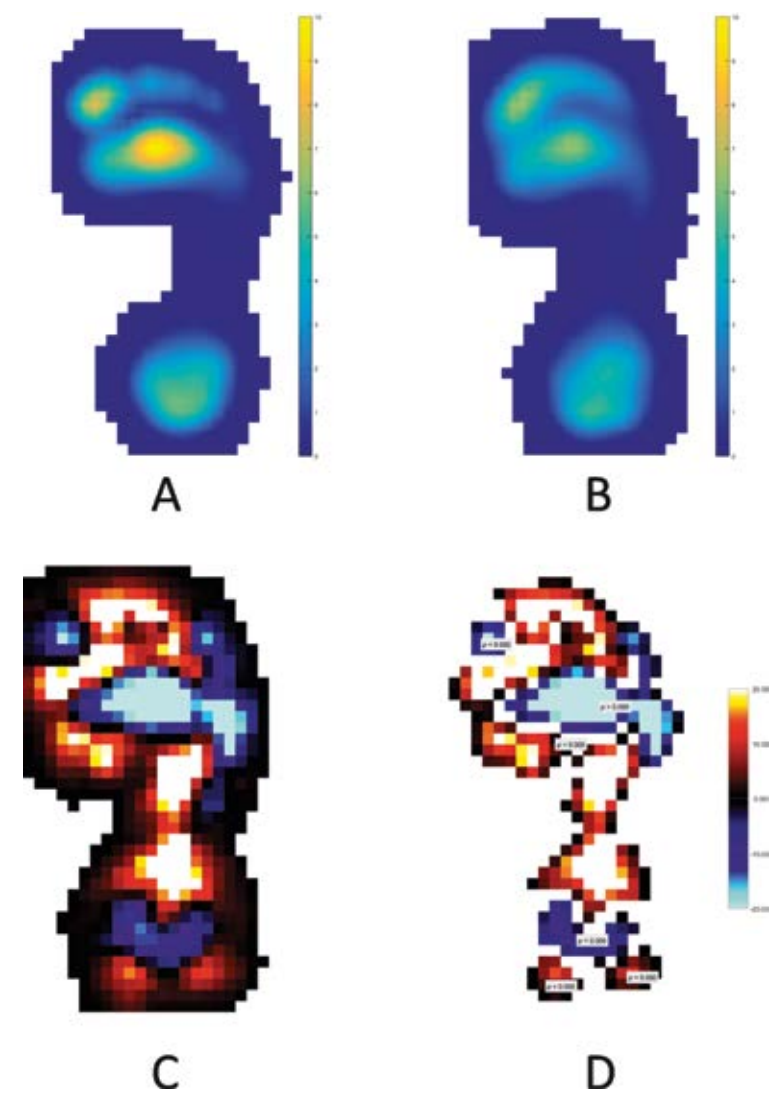


Figure 9
 Plots illustrating average peak pressure profiles from a single subject wearing three types of footwear, and walking barefoot. Note that the minimal and Kolhapuri footwear qualitatively resemble barefoot walking more than conventional footwear does.

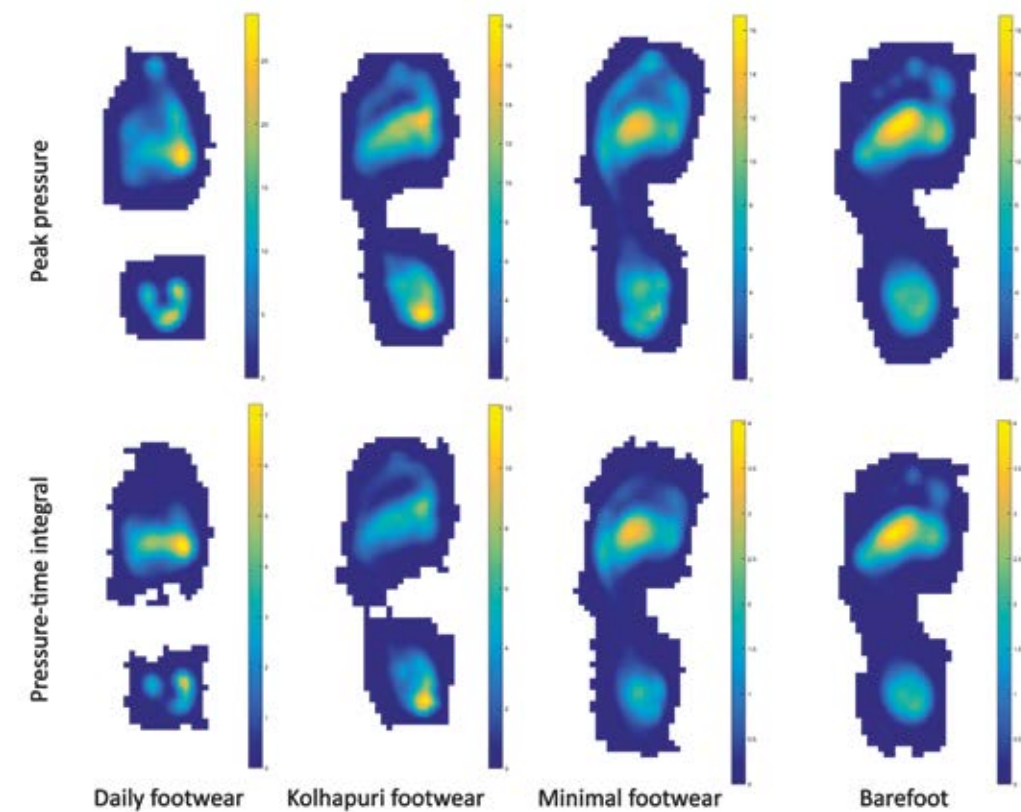
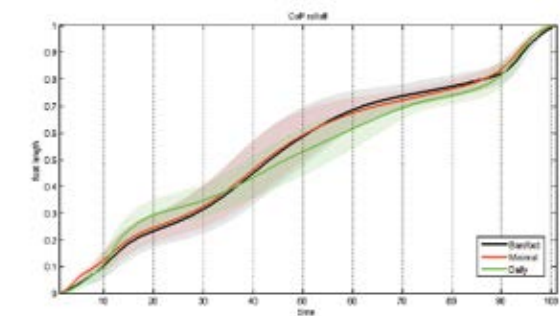


Figure 10
 Normalised displacement of the Centre of Pressure for 13 Western subjects walking barefoot, in minimal footwear, and in their own daily (conventional) footwear. Note that the barefoot and minimally shod conditions show a very similar displacement curve, whereas the conventionally shod (“daily”) curve deviates more. The latter involves a faster forwards displacement in early stance, and a slower displacement in midstance with regard to the two other conditions.



temporal “gait laboratory”. While this approach has been necessary, and fruitful, to collect the unique data of indigenously shod populations, it does limit technical possibilities. For example, two standard pieces of equipment of a conventional gait lab, force plates and a 3D motion-capture system, could not be used for weight and size considerations. A plantar pressure plate is portable and has been successfully used to study walking in field settings before (D’Août et al., 2009; Stolwijk et al., 2013).

The use of plantar pressure plates has been well established and poses few technical issues. While the magnitudes of the recorded pressures might not be as accurate as the forces recorded by a force plate, results from pressure plates provide a good overview of relative pressure distribution and are reliable, even between manufacturers (see Hafer et al., 2013). The main challenge with the use of footwear on a pressure plate is: how do these pressures relate to the pressures experienced by the foot? This question cannot be answered with certainty; this would require simultaneous recording of pressure data using a pressure plate and an insole system. (For overviews of the use of pressure plates and insoles, see e.g. Barnett et al., 2001; Low & Dixon, 2010; Giacomozzi et al., 2012; Abdul Razak et al., 2012.)

Few studies have addressed shod locomotion, running, on a pressure plate but they have focused on CoP displacement and not on a complete spatial analysis of the pressures themselves (e.g., Dixon & McNally, 2008; Greenhalgh et al., 2014). In the case of our indigenous footwear and commercial minimal shoes, however, the correspondence between shod and barefoot prints is striking, and even shod prints reveal a good degree of anatomical detail such as a clearly defined hallux. We hypothesise that the pressures as measured by the plate correlate closely to what the foot experiences. It should be noted that all soles (except for the “conventional”

shoes) are only a few millimeter thick and flexible.

The use of pressure sensitive insoles would allow for a direct measurement of foot pressures, and this has indeed extensively been used in non-minimal footwear, where a good correspondence between plate pressures and plantar pressures cannot be assumed. However, the use of pressure insoles would be a challenge in the barefoot condition and would require some form of gluing or use of a sock (e.g. Burnfield et al., 2004), potentially affecting results. The use of insoles in the shod condition and of a plate in the barefoot condition is not preferable if a direct comparison (as in this study), without technical confounding factors, is to be made. The use of pixel-based pSPM instead of zone-based analyses has been shown to give valid and objective results without prior anatomical assumptions (e.g., Pataky et al., 2008a; Pataky & Goulermas, 2008; Bates et al., 2013). Image registration between different shaped plots (e.g. barefoot versus shod) is not unequivocal, and although non-linear registration (Pataky et al., 2011) is a suitable solution for plots made by comparable morphologies, it yields irrelevant results when used to register shod and barefoot pressure plots (own data, unpublished).

Conclusion

Based on plantar pressure recordings, we conclude that Kolhapuri footwear, Nuvttohat footwear, and commercial minimal shoes, can all be considered “minimal footwear”, but there are significant differences to barefoot walking, the latter involving higher peak pressures.

Acknowledgements

We would like to thank Todd Pataky for developing and making available the pSPM code for MatLab. We greatly appreciate the collaboration of all participants in this study from India, Finland, and Belgium.

Conflict of interest

A full set of Vivobarefoot “The One” minimal shoes was donated to Catherine Willems by Terraplana/Vivobarefoot.

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DESIGN

DESIGN

Creativity and the environment

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Introduction

The following texts are reflections on feet and footwear design published during my PhD traject. These texts, which are not part of the formal scientific literature, were written for specific occasions and some of the material is recycled and repeated. I chose to include them for two reasons. The first reason concerns content. References to the India Report of Charles and Ray Eames, my own fieldnotes, and links to other objects give a deeper understanding of my work as a designer and anthropologist. The second reason concerns outreach and broader impact. The contributions are linked to exhibitions or design fairs and thus show that the knowledge gained during my PhD research is shared with a broader public. For enhanced readability I include slightly revised versions of the original texts.

The first contribution –*Creativity and the environment*– was published in ‘What exactly is making?’, a vision text of KASK, the Royal Academy of Fine Arts of University College Ghent. The publication was initiated by the design and architectonic design departments and published on the occasion of the 2014 Milan Design Week. The publication contains reflections on the research projects ‘Textile as a vessel for tacit knowledge’ by Clara Vankerschaver, ‘Future Footwear’ by Catherine Willems and ‘Research into the phenome- nological aspects of design’ by Hilde Bouchez. These three research projects were funded by University College Ghent.

The second contribution –*An anthropological reflection on form and matter*, co-authored with professor emeritus Rik Pinxten– was published in Dutch under the title ‘Over design als groeiproces: een antropologische reflectie op vorm en materie’ in the catalogue of Conflict & Design, the 7th Design Triennial of Design Flanders. The 7th Design Triennial in Flanders is an investigation into the social relevance of design and the responsibility taken by designers in our society –it provides food for thought as to how we are forced to interact with one another and manage our natural resources in radically new ways. Our text was the lead article for the exhibition ‘Conflict and Nature’, one of the four domains of the exhibi- tion. Rather than limit itself to presenting the work of the designers, this triennial turns the spotlight in the first place to design thinking and design processes, and it aims to actively involve the public in the event. ‘Future Footwear’ was one of the projects shown at the ex- hibition (www.conflictanddesign.be/en/projects/code/33). Rik Pinxten is professor emeritus of Anthropology and Religious Studies at Ghent University (Ghent, Belgium); he studies ‘Thought and Religion in other cultures’ (for instance, Navajo Indians in the United States of America, immigrants in Europe) and the philosophical grounds of social scientific research. He was my supervisor before becoming emeritus.

Creativity and the environment

“Of all the objects we have seen and admired during our visit to India, the Lota, that simple vessel of everyday use, stands out as perhaps the greatest, the most beautiful. The village women have a process which, with the use of tamarind and ash, each day turns this brass into gold. But how would one go about designing a Lota?... Of course, no one man could have possibly designed the Lota. The number of combinations of factors to be considered gets to be astronomical –no one man designed the Lota but many men over many generations.”

These are the words Charles and Ray Eames wrote in ‘The India Report’ in 1958. The Government of India asked for recommendations on a program of training in design that would serve as an aid to small industries, and which would resist the rapid deterioration in design and quality of consumer goods. American industrial designer Charles Eames and his wife and colleague Ray Eames visited India for three months and toured throughout the country, making a careful study of the many centres of design, handicrafts, and general manufacture. The India Report emerged as a result of their study and discussions. The Lota was chosen, according to Ray, ‘as a fixed symbol of utilitarianism in an evolving pattern of design. It could have been anything else from the day to day lives of the people.’

The same question as the Eameses asked about the Lota can be posed about the Jutti, a leather shoe with closed upper worn in Central and North India: ‘How would one go about designing a Jutti, and what happens when you treat the hide in a particular way, what happens to the hide and the Jutti’s during the different seasons, for instance the wet versus dry season? The material is far from a static entity with fixed attributes. There is no such thing as leather. There are many types of leather, even coming from the

same animal, and no two hides are the same. The tanners and artisans know what happens if they treat the hide in different ways. Even when human intervention stops, the hide still evolves and undergoes changes due to weather and light, being worn or not worn. The material I have seen and used mostly during my work as a designer-anthropologist in India is vegetable tanned buffalo hide. The shoemaking artisans in North India whom I worked with have a bag tanning process that, with the use of calcium, bark, and oils, makes the hide ready to use for their footwear. Observing and working with the artisans I wonder about:

- The size and the gender of the hands that manipulate the material;
- The way the material is to be used;
- The stiffness of the leather, the thickness, and the hairs;
- The shape of the footwear and the effect on the gait;
- The shape of the lasts (if any) used;
- The texture inside and outside in terms of feeling;
- Heat transfer –does it allow transpiration?
- How pleasant does it feel, eyes closed, eyes open?
- What is its cost in terms of working?
- How will the material affect the feet?
- How will it look as the sun reflects off its surface?
- How does it feel to possess it, to sell it, to give it?

How people make objects and how they use them is very much connected to the environment and the context. More than fifty years after its publication, The Eames Report is still frequently cited in contemporary discourses surrounding design. But the cultural association in the subcontinent of India of the Lota with hygiene and with washing oneself needs to be reconsidered. Two hundred years ago the Lota was still frequently used in Indian households to transport water.

Skilled practice in Sawai Madhopur © David Willems



With the installation of water pipes and taps the need to go to the well and to transport water is diminished. If the village women have access to running water at home, they don't need Lotas. Using or not using a Lota is not really a matter of choice, rather it stems from a lack of choice. The same accounts for the making of footwear in India. Should there be openings in other jobs or in higher education the artisans would not hesitate to change careers. The ones who work with leather (like butchers, tanners, shoemakers) are ranked below all other crafts because the material was and is considered ritually polluting in the Indian caste system. Our appreciation of the craft as such is often greater than that by the artisans themselves.

The focus of design could, instead, be on the preservation of a particular set of skills, on what it means to make things, including context and practices. The way objects are made in different contexts and with different materials can offer another perspective on what the role of designers and design researchers can be. Is it to foster creativity, ownership and empowerment, rather than appearing as a final authority on creativity? In my research on design and footwear it became obvious that different environments and climates lead to different footwear (which, in turn, might influence gait). From a biomechanical point of view, good contact between the surface and the feet is needed as input for the body to adjust to different positions and surfaces and to control its balance and stability. In the broader context –looking at the cultural and biomechanical aspects of footwear– I consider good footwear to be part of an unbroken proprioceptive loop that runs from the brain of the person wearing the footwear, through the feet, into the surface walked upon, and back through feet to the brain, allowing the individual to monitor and adapt the pattern of his or her gait.

We can return to Charles and Ray Eames'

conception of design as a bridge between the traditional and the modern has a new urgency and resonance in the face of a growing gulf between the urban, international locations for design, and the rural, vernacular basis of craft communities.

In the end, however, these concerns cannot be said to belong specifically to India. They point to the larger dilemmas associated with the economy of design. Future Footwear, as part of a vision text of the Royal Academy of Fine Arts (University College Ghent), wants to challenge and add nuances to oppositions between invention and convention and between innovation and tradition, and it wants to stimulate the capacity to combine traditional motifs in new and challenging ways and not measure the designer's abilities in terms of a singular innovation. It is a call to see creativity as immanent in all moments and, thus, a realization that creativity cannot be the preserve or property of a particular institution or of particular individuals. Collaboration between disciplines and a focus on the creation process taking into account the environment and the materials make the designer/maker aware of the future need for a balanced way of making.

I end this reflection with the famous phrases of the 'Bhagavad Gita', a section of the Mahabharata, which Ray and Charles Eames used as introduction to the 'India Report':

You have the right to work but for the work's sake only; you have no right to the fruits of work. Desire for the fruits of work must never be your motive in working. Never give way to laziness, either. Perform every action with your heart fixed on the Supreme Lord. Renounce attachment to the fruits. Be even-tempered in success and failures, for it is this evenness of temper which is meant by Yoga. Work done with anxiety about results is far inferior to

work done without such anxiety, in the calm of self-surrender. Seek refuge in the knowledge of Brahman. They who work selfishly for results are miserable.

Baghavad Gita

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**About design as a growth process:
an anthropological reflection on form
and matter**

What precedes:

Inari (North Finland), February 2011: it is cold, ice cold, the thermometer displays minus 16 degrees Celsius. The low sunlight hangs on to the snow carpet that transforms the seemingly endless plain into a serene and fairytale landscape. Every morning I walk to Sogsakk, a centre for Saami arts and crafts, two kilometres walking across a white plain. In Sogsakk I work for two weeks on tanning reindeer hides and making boots. With each step my winter boots sink half-a-metre into the snow. On the second day of my stay, I slip. I fall on a piece of wood hidden under a layer of snow, and my back hurts. I try to stand up and remove the snow from the bag holding my cameras and a computer. My unfortunate fall is only witnessed by a herd of reindeer.

Why do I sink so deep and slip, while the inhabitants of Inari expertly slide over the snow and effortlessly stay upright? Am I walking different, am I wearing the wrong shoes, or am I looking at the ground too much? The Saami wear reindeer boots with felt socks or dried grass inside. Only a little layer of skin and dried grass keeps their feet warm and prevents them from slipping. I ask myself whether there are any more reasons? After two weeks I realize that the ground, the reindeer boots, and an appropriate way of walking are all part and parcel of the same thing. At extremely low temperatures, their skin and hair keep the reindeer's feet warm. The same hides also keep the Saami's feet warm. The material used for the boots comes straight from the reindeer – four reindeer legs (one animal) for a pair of boots. The legs of the rein-

deer codefine the form of the boot. In Sogsakk I observe and imitate the skills necessary for making the boots at a gentle pace and under the expert eye of the Saami women. No instructions, no patterns. My first boots are ready after two weeks. It snows outside, I walk with slightly spread legs and bent knees and float over the snow, avoiding too much heel impact so as not to be recognized as a foreign visitor again. (fieldwork notes, Inari (FI) 2011, Catherine Willems)

What is the relationship between design, making things, and the environment? When we speak about design, this also refers to the use of tools and the thought process related to production.

In hylomorphism (cfr. the Greek hyle, “wood, matter” and “morph, “form) a theory developed by Aristotle, design always includes the reconciliation of form and matter. Throughout the centuries that symbiosis gradually got lost in Western society. Form was progressively considered as something imposed by someone with a specific image in mind. As a consequence, matter became merely a thing that got imposed upon, thus remaining passive and inert. The design as an idea is an immaterial imposed upon matter.

The philosophical term God's eye view places this vision in a broader context. From such a perspective, we view the whole universe, including all the living beings and produced objects, from the perspective of a sole outsider in the Western cultural and religious tradition. The pre-rational attitude inherent in this intuition automatically places mankind against all phenomena considered. In a stricter, more rational way of thinking, this perspective becomes the basis for objectifying everything, that is, to literally experience all objects outside the observer. Of course, anthropologists know that this human intuition is not universal but, mostly,

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limited to our western tradition. Within this intuition, design results in decontextualised and objectified products. According to Ingold (2013), making things with this intuition is considered to be a project.

We can approach ‘design and making/production’ from another angle too, a second intuition, where design does not precede production but where both are generated simultaneously within a process. Production is then seen as a growth process. Various authors have studied this growth process in the past two decades and have addressed a broad range of materials. A good example is how Ingold (2000) describes the duality between making and growing in his essay “On weaving a basket”. Baskets are woven with long, flexible twigs that are bent in the desired shape. The weaver first makes a spiral and the basket then progressively takes shape in his or her hands. The idea that a mould is used is not consistent with this scenario. The material is not purely formed, but is also self-forming. In the Finnish experience described above, neither the design nor the making comes first, they are interwoven as a double result of the same process. The hides of the reindeer legs are in transformation and are processed into a boot by the cobblers’ skills. The size and the hair of the reindeer co-define the final shape of the footwear.

Inspired by nature

Obtaining insight in design and design thinking today is a challenge involving many disciplines, and these disciplines are reflected in the skills of designers and their final products. Just like biomimicry or bio inspiration, this thought model tries to uncover natural processes so as to achieve new creations. Nature does most interesting things at a nanolevel but our inability to perceive that level –either with the naked eye or with a microscope– has left many questions unanswered. Why are the leaves of a lotus flower always clean? How can a gecko walk

on walls and ceilings? Is a spider’s web as strong as steel? Questions like these have led to all sorts of innovations through analysis at two levels: on a larger scale we examine how things work and on a smaller scale we examine the composition and properties of the materials involved. It is not the intention of bio inspiration to copy nature. Likewise, the labs where this type of research is conducted do not aim to reconstruct an exact copy of, for instance, a lotus leaf but to develop related attributes such as selfcleaning surfaces.

The combination of bio inspiration, smart materials, and knowledge of local cultures inspires new designs, but no science, no local population has ‘the’ key to the perfect future design model.

Design anthropology

What can anthropology –or, more specifically, design anthropology– contribute to a comparative study of design and what can it mean for the designers? According to Wilfried van Damme, the anthropological discipline can mean a triple added value to the development of a global perspective in the study of art and design. First, there is the involvement in the conceptual, epistemological, and methodological questions that arise when phenomena in divergent cultural worlds are studied. It is the discipline that takes culture as its object. Second, anthropology studies and compares communities and cultures across the globe. Or to state Hal Foster: ‘Anthropology is prized as the science of alterity’. And finally there is the empirical inductive nature of anthropology, its contextual focus, and its intercultural comparative perspective.

Regarding design anthropology we would like to emphasize the latter contribution and the use of action research as an active research method. By immersing ourselves in the work of craftsmen, we can observe the creative process from within. On the one hand, we try to collect the implicit knowledge that is in-

Leg skin of reindeer © David Willems



dispensable for making a specific product; on the other hand, we try to gain better insight into the context of the material that is used and the products that are made.

In design anthropology the material and the process of making have a bridging function. We say that design is embedded in a broader corpus of social knowledge relating to the value of that craft, based on ideas about the body, gender, environment, and locally available resources. If we focus on the shaping processes of design in a specific environment, we can avoid ‘pseudo ethnography’. We refer again to Hal Foster who is sceptical about the possible effects of using anthropology in art (and design). ‘For the quasi-anthropological artist (in our case designer) today may seek to work with sited communities with the best motives of political engagement and institutional transgression, only in part to have his work recoded by its sponsors as social outreach, economic development, public relations... or art (design)’.

There can only be empowerment between the participants if they share the creative processes as equals and when limited engagement (for example because of short time field work) is avoided. Those processes should, in other words, not be the exclusive knowledge domains of individual researchers/designers. We want to encourage creativity, ownership, and empowerment and not appoint ourselves as the ultimate authority in the field of creativity. In action research, the designers –that is, both the craftsman and the researcher– do not appropriate the results. They share authorship so that the project can lead its own life. Design anthropology is based on commitment and is always an anthropology ‘with’ and not ‘of’ people. Practicing anthropology ‘with’ people means that, during research, one learns with and from people and that one uses various experimental activities, tools, theo-

retical concepts, and materials. Using action research as a method –with the material as a base– also entails that the familiar becomes foreign and that non-obvious aspects are placed against a broader background.

Good design starts with the analysis of the complete history of the material and not with the analysis of its condition at the time it is processed into a product. If we want to reach sustainable designs, we cannot avoid the earlier history or the second life of the materials.

Involvement as a key to achieving design This intrinsic participating design anthropology follows the praxiological approach of Bourdieu as regards knowledge theory. In the so-called ‘method battle’ from about 1930 to 1980, the positivists (behaviourists, structuralists) and the phenomenologists (participating observation, empathy) fought each other. Each said the other was not ‘scientific’. The positivists only accepted what was externally observable and measurable as a source of (scientific) knowledge. They therefore rejected as unsound anything that was learnt from experience and conversations with the informers. The phenomenologists maintained that the researchee was a human subject like the researcher. Therefore, through empathy you can become ‘like the subjects of the study’ and learn to experience and describe his culture from within, as it were. Bourdieu notes that both approaches are unidirectional: both options place the action of categorizing, interpreting, and describing only with the researcher. One ‘objectifying’ and the other ‘subjective’, but always without completely integrating the research. With his praxiological vision, Bourdieu states that all human and social scientific research is, in fact, a form of interaction and, therefore, deeply depends on the quality of the interaction between researcher and researchee. It is more correct to involve the researchee as extensively as possible in that interaction and in the selection, inter-

pretation, and evaluation of ‘facts’. It can then even be decided to make the subjects under study co-authors of the description.

It is obvious that the view of social sciences as an interactive process allows much more room for complexity and for refinement of the various intuitions, because the researcher learns to deal auto-critically with his or her own view.

The two intuitions described above can be seen as two forms of interaction, where-as they would be mutually exclusive in a unidirectional approach (both positivist and phenomenological). Theoretical reflection on the nature of scientific research with people provides a broader philosophical framework in which design anthropology can position itself. It is important to make this reflection, because design and design anthropology as disciplines must of course be considered as thinking and action methods belonging to a time scale and a thinking tradition and are not contextless occurrences.

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SHOE DESIGN AS CULTURAL HERITAGE



SHOE DESIGN AS CULTURAL HERITAGE

Nuvttohat, perfect for feet!

Catherine Willems

Submitted *Volkskunde, driemaandelijks tijdschrift voor de studie van de volkscultuur*, 2015. Special issue on intangible heritage and diversity

Abstract

The Saami, living in the northern parts of Norway, Sweden, Finland, and northwestern Russia (also known as Sápmi) use the *nuvttohat* during winter time. The *nuvttohat* is a winter boot made from local available material (i.e. skin of the reindeer fur leg). The boots provide the ultimate protection from the environment while respecting the natural foot anatomy. The design project described here aims at recreating the boot for another environment, i.e. to make it appropriate for new terrains. It also questions how the process of making creates knowledge (incl. tangible and intangible knowledge). The making of the *nuvttohat* is understood in the context of skills transfer (as a form of intangible cultural heritage) and learning from person to person, from one generation to another. *Nuvttohat* are part of the Intangible Cultural Expression of the Saami. What does it mean for design researchers that are not part of the Indigenous Saami community to make and remake boots that are part of the cultural heritage of the Saami? The article explores possible ways of dealing with (in)tangible cultural heritage.

Keywords:
Saami artisans
tangible heritage
intangible heritage
skills
nuvttohat fur boots
thermal protection
design collaboration

February 2015:
Inari, The Saami Education Centre¹
“The purpose of this visit is to remake nuvttohat², a reindeer skin boot, with Saami craftswomen. In addition to functioning perfectly with the foot, the ‘nuvttohat’ keep the feet warm even at extreme low temperatures. With simple design interventions we want to make the boot suitable for urban wear. During the visit we had a discussion on the intellectual property of the boots and the making of boots inspired by the ‘nuvttohat’. After explaining the goals of my PhD and our visit, a discussion started on the characteristics of the boot as part of their intangible cultural heritage and on the skills needed for making the fur reindeer.”

The Saami, living in the northern parts of Norway, Sweden, Finland, and northwestern Russia (also known as Sápmi), are the only indigenous people in the European Union to have their own language, culture, means of livelihood, and identity.³ According to the 2007 United Nations Declaration on the rights of indigenous people, the Saami have the right to:

“maintain, control, protect and develop their cultural heritage, traditional knowledge and traditional cultural expressions (TCE), as well as the manifestations of their sciences, technologies and cultures, including human and genetic resources, seeds, medicines, knowledge of the properties of fauna and flora, oral traditions, literatures, designs, sports and traditional games and visual and performing arts. They also have the right to maintain, control, protect and develop their intellectual property over such cultural heritage, traditional knowledge, and traditional cultural expressions.”⁴

The culture of the Saami includes language, reindeer herding, musical expressions such as Joik⁵, the Saami costume (Saami gákti), and reindeer skin boots as part of Duodji⁶ handicrafts.

In this article we treat the Saami reindeer boots as traditional cultural expressions (TCE), seen from the point of the Saami as indigenous people and from my own point of view as a design researcher. What does it mean for design researchers that are not part of the Indigenous Saami community to make and remake boots that are part of the cultural heritage of the Saami? In the first part of this article I report on features and walking properties of the nuvttohat boot. In the second part I focus on our collaborative practice-led research on the making of fur reindeer boots. The convention on safeguarding Intangible Cultural Heritage (ICH) and the issue of copyright is dealt with in the third part. In the fourth and last part I reflect on the use of knowledge related to the making of nuvttotat as part of ICH, to conclude I look into ways of further design and academic collaboration.

Saami footwear –Northern Finland

In winter, the inhabitants of Northern Finland use nuvttohat, a fur boot made entirely from reindeer skin. The reindeer is slaughtered for the meat and the legs are used for the shoes. Each reindeer yields a single pair of reindeer boots. Gamagottur (North Saami) means the skin of all of the four legs of a reindeer. The skins can be taken from an animal slaughtered in the period from autumn to spring, depending on what they will be used for. The use depends on the length and the thickness of the fur. Leg skins with short hair are chosen to make boots for special occasions and are usually from a reindeer of white colour. Skins with longer hair are used for daily footwear and can be taken from a reindeer of yellowish grey colour.

Leg skins taken from animals slaughtered in the autumn have short hair, but the skin itself is thick. The lifted nose –once functional for holding the ski– is disappearing because of the use of snow scooters. The footwear is handmade and no nails or adhesives are used. There are various ways of sewing the reindeer boots, which is traditionally done with the tendons of the reindeer. The opposite hair direction on the outsole provides a natural anti-slip on the snow. The boots are used during colder weather (–10 to –30 °C or lower) when the water is frozen and when there is a lot of snow. Interviews confirm that the fur outsole of the footwear is not suitable for rainy days and temperatures around or above zero⁷. Brogue bands, vuaddagat, are used to close the boot and to keep the snow out. The pattern of the woven (or plaited) shoe bands refer to the different Saami communities, as well as to the type of boot, the gender of the wearer, and the use of the boot, for instance ceremonial or for daily work. Another feature of the footwear is its flexible outsole and its light weight.

The following testimony was recorded while driving from Inari to Kaamasmukka (in Northern Saami Gámasmohkki), a village in Finland in the municipality of Utsjoki. The day is February 8th 2011 and the temperature is minus 25 °C. During the one and a half hour drive a local informant talks about fur boots.

“My husband’s elder brother’s wife is a very close friend to me, we are relatives now and very often we talk; every year the same things according to the seasons and somehow you know year after year certain things come back for example: ‘on walking with the fur shoes’. The conclusion is always this: ‘don’t you feel awful when you put the regular shoes on because they are so heavy?’ When you are wearing the fur shoes it is air and so light. This conclusion comes every year

after the winter season, when switching to the normal shoes again.”

The low weight is an important feature of the reindeer fur boots, combined with the thermal protection of the hides it makes the boot one of the lightest and warmest winter footwear available. Inside the boot traditionally *kinkaheina* (dried grass) is used instead of socks because of the good insulation. We measured the thermal conductivity of the reindeer fur with and without grass. The thermal resistance –also known as thermal insulance– of the reindeer fur hides doubles when adding the grass (Peter 2013⁸). We compared the gait of 42 people living in and around the village of Inari when walking barefoot and when walking with reindeer boots.⁹ The results show that reindeer boots provide the ultimate protection from the environment and respect the natural shape of human feet and that they do not interfere with the natural anatomy of human feet. Several respondents reported less lower back pain when using their own footwear.

But it is not only about the boots: walking in snow demands a different way of moving, of gait. Evidence of the walking skills needed in snow is shown below in a testimony of a local informant (February 2011 – driving from Inari to Kaamasmukka):

“We were all having fur shoes when we were walking and working with the reindeer. My husband told me to go and fetch something from the snowmobile, so I had to go underneath the fence and then take the track of soft snow, a new track. I dropped, dropped, dropped. And of course I didn’t see anything –I was just doing my walk. In the evening this old couple comes visiting our house. And then they said: ‘yah you were doing this work in the forest’. I said: ‘how do you know that we were doing this work in the forest?’ They said: ‘we saw you walking there’. I said: ‘you saw me

walking?’ ‘Yes, you were on your way to the snowmobile’. And then they gave me a very nice look and I knew straight away we didn’t need to talk. They said: ‘you can’t walk on the snow, we saw you crawling in the snow’. Eventually I have learned to walk on the snow, it is the touch with the snow. You just walk so that you don’t drop in the snow. Each person has to catch up his or her own system, I have learned it now, but the thing is that, for instance, my husband has had this walk since his childhood, from the very beginning, because he was born with the snow and with walking on the snow... it means also that already the beginning of the approach towards the snow is different because it is there permanently, it is not something that you have to win.”

Now we know the boots perform best in their natural environment, on snow, and when the temperature is below 10 °C. In the next chapter I describe the process of making ready to wear reindeer boots suitable for an urban environment using the same local materials and techniques.

A collaborative practice-led footwear research

Working with the fur legs requires a lot of experience. First of all, one needs to have the knowledge for selecting good fur from the right season. A local informant says:

“Each time you wonder, how does this shoe live in this life with this person, or whether the fur will come off. You think about what time of the year it was that the hairs came off. How did the fur feel before you peeled it off, I mean before the killing? So this process of coming to the perfect skin and leather is, let’s say, again a question of individual experience. (February, 2011)”

Second, one has to consider the size of the leg skins. The indigenous model follows the shape of the leg skins available and thus informs the design. While making a prototype for the newly designed footwear I realised we didn’t make use of the skins in an efficient way. One of the artisans states:

“Also I have to say that it is like solving a puzzle to work with reindeer fur; I have to find matching colours and thicknesses of fur. Which I did not do in this proto as well as I should have, because I thought it was only a prototype. And if I may say so, the design is not easy considering the sizes and shapes of the leg skins; for example I had to use pieces of nine leg skins! That would make 18 leg skins per pair of shoes size 42. Adding the working hours per pair, I estimate at this stage it would take the whole day to make one pair. May be later a little less. These will be expensive shoes. (February, 2015).”

During three visits to the town of Inari (northern Finland) we observed and learned with Saami crafts women while making reindeer boots and walking with the boots. The aim of the collaboration is not to make a study of craft practitioners but to make boots with them, at the same time safeguarding the skills of making the boots. We move away from the textual perspective –for instance written manuals –and focus on tacit knowledge. Tacit knowledge –tradition, inherited practices, implied values, and prejudices– is learned through applied practice. Polanyi summarizes the idea in his work The Tacit Dimension (1966) with the assertion that “we can know more than we can tell”. Apprentices, for example, work with their mentors and learn craftsmanship not through language but through observation, imitation, and practice. The above testimonies show, however, that knowledge is not only in the making but also in the wearing of the footwear.



Our first visit –February 2011– was dedicated to learning how to make the traditional boots in a ten-day footwear course at Sogsakk, the Saami Education Center. During the second visit –November, 2011– we (that is, my supervisors of biomechanics¹⁰ and I) researched the biomechanics of walking by comparing barefoot walking with walking with reindeer boots. For the design of the new (X-Indigenous) footwear I visited Inari, Sogsakk, for a third time in 2015. The design related aspects were elaborated in close collaboration with two Saami artisans and with Vivobarefoot, whose founders joined us on a field trip to Inari (February 2015) to make nuvttohat inspired boots respecting the natural anatomy of the feet. When looking at the models –the indigenous versus the newly designed models– one would say that only the material is the same. For use in an urban environment, however, we had to reflect on the material used for the outsoles. The newly designed prototypes feature a Thermoplastic polyurethane (TPU) outsole instead of the reindeer fur.

Safeguarding intangible cultural heritage

Differentiating between intangible and tangible heritage might be confusing. Craft items, such as boots, are tangible, but the knowledge and skills to create them are intangible. Tools are tangible, whereas patterns are intangible if still in thought but tangible when drawn (Kurin 2004). Safeguarding intangible cultural heritage (ICH), according to the Convention for the safeguarding of the intangible cultural heritage (article 2.1, 2003)¹¹, must be done with the permission, co-operation, and substantive involvement of and decision-making by the relevant communities and practitioners. The convention describes ICH as:

“The practices, representations, expressions, knowledge, skills –as well as

the instruments, objects, artefacts and cultural spaces associated therewith– that communities, groups and, in some cases, individuals recognize as part of their cultural heritage. This intangible cultural heritage, transmitted from generation to generation, is constantly recreated by communities and groups in response to their environment, their interaction with nature and their history, and provides them with a sense of identity and continuity, thus promoting respect for cultural diversity and human creativity.”

These intangible expressions are often seen as being in the public domain and thus free for anyone to use. Indigenous peoples, local communities, and many States argue that this opens up traditional cultural expressions (TCEs) to unwanted misappropriation and misuse. Also the Saami Council wants more attention for the protection of TCE.

The following quote shows the concern of the Saami Council:

“The Saami Council –and other indigenous organizations– have repeatedly in this Committee stressed and given concrete examples of ongoing thefts and disrespectful use of indigenous TCEs as this debate continues. This theft is made possible by a legal system that is not ours, that we had no part in creating, and that allows others to come in and steal elements of our culture, without paying any attention to our views, needs or interests. The Saami Council urges the Secretary of the World Intellectual Property Organization (WIPO)¹² to direct increased attention to the issue of protection for TCEs in the so-called public domain in its future work.”¹³

In this context I like to highlight the importance of copyright and the work done by WIPO that considers TCEs as the forms

X-Indigenous boot © David Willems
The making of © Catherine Willems



Inserting *kinkaheina* (grass) in the boot © Kristiaan D'Août
Overshoe to protect the fur boot © Kristiaan D'Août
X-Indigenous fur boot © Virpi Jaasko
X-Indigenous fur boot featuring a rubber outsole © David Willems



in which traditional culture is expressed. According to WIPO the cultural expressions form part of the identity and heritage of a traditional or indigenous community and are passed down from generation to generation—they include design and handicrafts and many more artistic and cultural expressions. In the ‘Protection of traditional cultural expressions: an EU perspective’, Arnesen (2014) demonstrates that the protection of TCEs under existing copyright law is impeded by a range of issues. He explores the challenges of protecting TCEs using Saami Yoik as a case study. The relevant intellectual property regime when seeking to protect the Yoik is copyright law. We analyse the nuvttohat as a TCE following the arguments of Arnesen.

In general, copyright is described as a form of intellectual property, applicable to any expressed representation of a creative work. The intention of copyright is to recognize an individual author or a group of authors and protect their creation. The challenge reveals itself upon application to the fur boot nuvttohat. The fur boot is defined as an expression handed down from person to person, from one generation to the next, and as constantly evolving and being recreated within the Saami community. The concepts found in copyright law for boots and the making of the boots are by definition contradictory. The boot simply cannot be attributed to an individual author or a group of authors. Another obstacle is that there is not ‘one’ design. Reindeer herding people design their fur shoes for specific (local) conditions and needs, which are not constant across the community. To give a contemporary example: with the use of the snowmobile the reindeer herding people adapted the design of their fur boot. In snow they prefer to walk on fur outsoles because they provide thermal comfort and natural anti-slip; on a snowmobile, however, they protect the fur boots with an overshoe for better grip and to prevent the hairs from falling off. The lifted nose, a

typical feature of the boot, is then omitted in order to fit into the overshoe.

If the boot is to be placed under the protection of copyright law, it has to meet the conditional requirement of originality. Under the hypothesis that the boot, even if it at one point in time was protectable by copyright, has fallen into the public domain, the concept of originality can only be applied to the small changes it is bound to undergo through constant evolution, development, and recreation in the Saami community. Do these small changes each meet the requirement of originality?

The last obstacle I want to highlight when subjugating a TCE to copyright law is the limited duration of protection afforded. The fact that copyright is subject to expiration means that the attainment of copyright for a given TCE will not result in a protection that meets the expectations of indigenous peoples and would not grant a lasting protection of their TCEs.

It is of interest to consider the protection of cultural heritage not only in the context of international organizations, such as WIPO, which find their origin and need in globalization, but from the more traditional point of view of local, autonomous communities. Thuen (2004) describes in ‘Culture as property? Some Saami Dilemmas’ that a rule of collective right, individual autonomy, and equality used to be in effect. This ancient system, known as *Siida*, refers to the social organization of the Saami communities, which had common sources of livelihood and common territories. This organization is built on shared customs and principles of how individual interests are to be negotiated and reconciled with the interest of the local community. The important notion is that in local communities cultural heritage can be preserved over time through informal organization based on shared ideals of autonomy, equality, and flexibility. This interface of

the individual and the collective should be explored further as the safeguard of cultural heritage.

Consistent with this ancient *Siida* system, one could argue that in the long-term heritage is safeguarded as much by economic motives as by copyright protection. By earning money through the practice of their traditions, indigenous artists and craftspeople have supported their families and developed new products and markets for their skills. Perhaps more than anything else, that kind of success will encourage the next generation to continue to practice and carry their heritage forward.

The boots as ‘intangible’ cultural heritage: final reflections.

Would putting ‘the’ fur reindeer boots on the list of Saami Intangible Cultural Heritage enhance creativity? Exclusive thinking and refocusing on alleged identity does not guarantee a respect for diversity. Pinxten gives historical examples where creativity reigns at times of international and intercultural openness.¹⁴ These show that it is important to be open to foreign cultural elements. From this point of view, it might be limiting to extend public legislation to include measures against the investigation or artistic elaboration of cultural elements that belong within the context of indigenous cultural heritage. The same accounts for collaborations between different communities: restrictions might, eventually, impoverish the ICH, with possible isolation of the group and musealisation of, for instance, the material objects that are part of ICH.

Still, it is understandable that indigenous people protest when their cultural representations are (or are perceived to be) exploited by external parties. The making of reindeer skin boots is as much a part of the Saami indigenous clothing tradition as other items of clothing, like coats and leggings,

made from the same material. All reindeer herding peoples have their own design of fur shoes for their specific conditions and needs. When snowmobiles came into use among the reindeer herding people the design of the boot changed, as explained in the previous paragraph. But it is also a fact that skin boots and clothing of this general kind have been worn by people all around the circumpolar North. Thus while details of style and stitching may vary, there is nothing about them that is exclusive to Saami heritage. Mixing the boots with elements from other cultural areas, such as adding a waterproof outsole, is illustrative of the decontextualization, in the sense of making the boots appropriate to new terrains. The Convention is aware of this dynamic process as it states that ICH is constantly recreated by communities and groups in response to their environment, their interaction with nature, and their history. Recreating should be seen in a wide perspective. As Pinxten (2015) put it, if the Convention wants to deal with reality with respect to diversity, recreating should mean being open to learn and implement new things.

The aim of this article is not to come up with a single model of how to deal with ICH. This discussion is open on a worldwide level and no one has definitive answers yet. With this design experiment my collaborators and I look together with community members for answer, trying to avoid mistakes of the past. We aim for long term engagement and want to avoid the ‘hit and run’ strategy of outsiders gathering knowledge that is then used for different academic or economic purposes without the involvement of the community and without paying attention to the views, needs, and interests of that community. What I propose is a way of working that requires close interaction and the build-up of shared understanding and trust. We acquire knowledge through practical experience in the relevant context. In my view this is not possible without the permission, co-operation, and substantive decision-making

involvement of the relevant communities and practitioners. I try to find solutions that are sustainable for the communities and refer to the self-reliant, durable, and collaborative or cooperative commons as described by Rifkin (2014). The commons refer to a new economy, ‘a third way’ where collaboration, sharing, ecological concern, and human connections become more and more important. Social entrepreneurs are shaping economies to be more energy efficient and collaborative.

Considering my double position as anthropologist and designer I propose to work on different levels:

On an academic level the output of this project will consist of an exhibition of the different indigenous models and the newly designed footwear. The gathered biomechanical and design related knowledge will be shared with the population who participated in the research and with everybody who shows an interest, in the form of lectures and exhibitions. Conversations with –the Saami Museum in Inari– started in February 2015; the aim being to organize an exhibition in 2016. The project will also develop recommendations for future design training, taking into account a critical engagement with skill transfer as a form of intangible cultural heritage.

On a design level the boots included in this article will be elaborated further in collaboration with local artisans, Vivobarefoot, and myself. The newly designed models will be brought to market for winter season 2016–2017, using a strategy of personalised online or concept store sales so that the artisans are able to produce to order thus minimizing waste. In addition to providing income to the artisans, a profit contribution will be used to support crafts communities. The latter, could be in the form of offering a percentage on the sales to the Saami Duodji (the Saami craftsmen association), or in the form of scholarships for young (Saami) crafts students.

The ability to adjust to a changing environment is inherent to all cultures and ways of life. In what may be viewed as an extension of Siida to modern open societies, the respectful use of indigenous cultural expressions –through transparency, willingness to collaborate, and respectful interaction– are the key factors to make this design collaboration a success. In the end this project wants to tell two positive stories, one about bringing back a more natural healthy movement and gait and another about safeguarding the skills of local artisans in times of increasing globalization.

Notes

___ ¹ For this visit, I – as an anthropologist and designer – was accompanied by Asher Clark and Galahad Clark, the founders of Vivobarefoot. Vivobarefoot is a UK based shoe-design company that in 2004 became pioneer of the barefoot movement. The company makes constructions specifically designed for varying terrains, and activities –from high performance running shoes, off-road and trail running shoes, to work and kids shoes– and their vision for walking aligns with the multifaceted focus of the PhD Future Footwear. ‘Future Footwear’ is a six-year PhD project in the arts funded by the University College Ghent, School of Arts, KASK in collaboration with Ghent University, University of Antwerp and the University of Liverpool. The research explores the relation between materials, skills and creative practices of designing and walking.

___ ² Idem¹

___ ³ This recognition is most clearly presented in the establishment of the Saami parliaments and the Saami Council as a cooperative organisation of the Saami parliaments. Every four years they are democratically elected in Norway (since 1989), Sweden (1993) and Finland (1996). In Finland the Saami parliament has implemented Saami cultural autonomy since 1996. Section 121 of the Finnish constitution, which came into force in the beginning of 2000, states: ‘Cultural self-determination with regard to language and culture is safeguarded within the Saami homeland in so far as it is provided for in the law’ (The Saami 2005).

___ ⁴ Article 31 United Nations Declaration on the Rights of Indigenous Peoples, which was adopted by the UN General Assembly on 13 September 2007, proclaims the rights of indigenous peoples to their traditional cultural expressions (TCEs). The Saami people have the status of indigenous people as a result of this the United Nation’s Declaration.

___ ⁵ Yoik, monophonic vocal music, is the traditional form of Saami chanting (The Saami 2005).

___ ⁶ The word Duodji means an act, activity or product although today it is mostly used to refer to handicrafts. The Saami were and are well known for their handicraft skills. Traditionally handicrafts are divided in men’s work and women’s work. Even today, in some regions the people believe that it is the job of the women to work with soft materials while men work with hard ones (The Saami 2005).

___ ⁷ Based on interviews with 42 respondents who participated in the biomechanical research (November 2011). The respondents were recruited from Inari and Utsjoki. All subjects had own reindeer fur boots. The subjects participated on a voluntary basis, were informed of the protocol, and gave written informed consent according to the protocols approved by the ethical committee of the University of Antwerp. Prior to the recordings they answered a short questionnaire about footwear habits and recent injuries of feet and ankles.

___ ⁸ Determination of thickness of the reindeer hides, of water permeability, of resistance to surface wetting, of thermal insulation and of friction were studied at the Textile Department of Ghent University between November 2012 and February 2013 (Peter 2013).

___ ⁹ The interdisciplinary PhD ‘Future Footwear’ includes the analysis of gait over two conditions: 1) walking barefoot; and 2) walking with reindeer fur boots. To measure the differences plantar pressure recordings (RSscan Footscan) were executed (Willems, et al. 2015).

___ ¹⁰ Dr. Kristiaan D’Août, Faculty of Health & Life Sciences, University of Liverpool and prof. dr. Gaëtane Stassijns, Physical Medicine and Rehabilitation, Antwerp University Hospital.

___ ¹¹ Examples of intangible cultural heritage include for instance shrimp fishing on horseback in Oostduinkerke (Belgium), weaving skills in the United Arab Emirates, and storytelling from China. Consulted on June 12th 2015: <http://www.unesco.org/culture/ich/en/convention>.

____ ¹²In 2000 the establishment of the WIPO intergovernmental committee on intellectual property and genetic resources, traditional knowledge and folklore (IGC) marked a step towards actually achieving a protective scheme towards the rights of indigenous people (<http://www.wipo.int/>).

____ ¹³Statement of the Saami Council to the chairperson of the World Intellectual Property Organization Intergovernmental Committee on Intellectual Property and Genetic Resources, Traditional Knowledge and Folklore (March, 2004). Consulted on June 12th (2015): http://www.wipo.int/export/sites/www/tk/en/igc/ngo/saamicouncil_igc6_tce.pdf

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THE UNFASHIONABLE FOOT



THE UNFASHIONABLE FOOT

Sustainable footwear
for environment and body

Catherine Willems, Clio Gydé and Dirk van Gogh

Introduction

A commitment to walking and running on two legs distinguishes humans from apes and has long been the defining adaptation of the hominins –the lineages that include both humans and our extinct relatives. This form of locomotion (bipedalism) has been around for millions of years, and we have been unshod (barefoot) for more than 99% of that time (Trinkaus, 2005).

Footwear as it is known today is a relatively recent development in human culture, with archaeological evidence dating back the middle Upper Paleolithic in parts of Europe (Trinkaus, 2005). Modern footwear has evolved from simple foot coverings –primarily for thermal protection in colder climates (Kuklane, 1999) and mechanical protection in all environments (Zipfel and Berger, 2007)– to more elaborate devices reflecting different cultures, fashion and behaviours (Ashizawa et al., 1997). Since decades, several billions of shoes are being consumed each year worldwide and many end up in landfills when their functional life has ended (Staikos and Rahimifard, 2007). Unsustainable consumption and production patterns in the developed world have led to an increased generation of waste.

This paper investigates two related questions, both stemming from a broader study of the use of context-related knowledge in footwear design. Considering biomechanical and anthropological dimensions, we are studying the design-related aspects of two types of indigenous footwear and their relevance for contemporary footwear design. We analyse the embodied skill (Ingold, 2000) of making footwear in the respective communities and the contribution this offers to the design of contemporary footwear that is sustainable for body and gait and for the environment. The questions are: How can we design footwear that re-spects our natural anatomy while offering a maximum of protection? And, how can we create footwear that does not degrade the source and sink functions of our environment and that, thus, keeps our natural capital intact?

In the first part of this article we sketch the theoretical framework. We position ourselves in the design research landscape and explain our vision on ‘design and making’. This is done by comparing two traditions in creativity research, namely ‘individual’ versus ‘collective’ creativity (Sawyer, 2012).In the latter, ‘design and making’ are examined from an ‘internal position’, by seeing people amongst the materials of their craft (Ingold, 2013). Connected to this theoretical point of view is the practice based method of research. Action research is a method of anthropology that combines observations and engagement through making. We explain what sustainable footwear design means for the body and the connected gait pattern and what it means vis-a-vis the environment.

In the second part we present and describe two examples of indigenous footwear that is sus-tainable in this broad sense (that is, both for body and gait and for environment). We worked with the Kolhapuri artisans in Athani (India) and with the Saami artisans in Inari (Finland) to better understand the design processes in their context. We use this understanding to isolate pertinent features of the footwear.

The third part describes the new footwear, the tools and the material. Based on the features of the indigenous cases we re-create a sandal and a winter boot in four different production settings from handmade, to semi-handmade, and to 3D printed footwear.

The fourth and final part is an analysis of the new designs and a comparison with the indigenous cases. We compare the three levels of production and evaluate their effect on the environmental and biomechanical aspects of creating footwear. Can the role of the ‘ancient’ be more than just a form related inspiration in the design of new footwear? Looking at the skills of making and the ways of wearing footwear in its (cultural and physical) context puts footwear design in a broader perspective and enables one to re-consider ways in which feet, footwear and their design are interconnected.

1. Individual versus collective creativity

In Explaining Creativity, Sawyer (2012) states that creativity researchers are scientists who study how new things are created by human beings. In addition, the researchers also seek to answer an applied question: “How can we use these insights to provide advice to people, groups, and organizations about how to increase their ability to generate new and useful things” (Sawyer, p. 429). Following Sawyer (2012) we can group the creativity researchers in two major traditions: one follows an individualistic approach, with focus on the individual’s creative process, whereas the other follows the sociocultural approach, which studies how groups collectively generate innovation.

Design researchers in the first group have an expert mindset. Design with this mindset is mainly a problem-oriented activity. There are hundreds of articles and text books giving advice and describing tools to foster one’s own creativity. According to Verhaert and Braet (2007) the core skill of an individual designer is having ‘the ability to generate ideas during a design process that is simultaneously inspired by technological, economic and human sciences’. According to these authors a professional designer should have the talent and skill to handle all those aspects simultaneously while originating, creating, and making new objects. With (wo)-men living in a constantly evolving life and work environment each ‘state-of-the-art’ artefact is bestowed with new functions, designs (shapes), and applications (Rosen-

man et al. 1998). For a designer to come up, time and again, with innovative artefacts (Higgins et al. 2002) that distinguish themselves from any other existing product, when and wherever and in whichever cultural context it was designed, requires creative and interdisciplinary skills (Hsiao et al. 2004, Sternberg, 2005). Designers in this approach create new artifacts ‘for’ consumers and not ‘with’ consumers. Visual innovation in form and material become very important. ‘But design is not the act of amazing an audience with the novelty of forms and new materials, it is the originality that repeatedly extracts astounding ideas from the crevices of the very commonness of everyday life’, says Kenya Hara in Designing Design (Hara, 2014).

The sociocultural approach, on the other hand, emphasizes context and process over object. Within this approach many authors have studied the complex networks that support individual creativity. Dul and Ceylan (2011) summarized findings of numerous studies looking at the effects of environmental factors (such as furniture, color, light conditions, sound, and smell) on individual creativity. It was not until the 1990s that the role of collaboration in creativity and innovation began to be explored seriously (Csikszentmihalyi, 1996). Especially over the last ten years we see a trend towards collaborative design and creation that focuses on the process itself rather than on the final product, ultimately questioning the role of the sole geniuses (Sanders, 2012). This is not to deny the creative agency of the designer. This approach moves beyond the individual to consider the social and cultural contexts of

creativity, including the role of collaboration in the creative process. A sub-discipline of contemporary anthropology, design anthropology (DA) is embedded in this sociocultural approach and focuses on the processes of design and creation from an intercultural comparative perspective. In collectivist societies, as opposed to individualist societies, the creator is considered as the apotheosis of the group (for instance, Benedicte, 1961).

Design is embedded in a broader corpus of social knowledge relating to the value of a specific craft, based on ideas about the body, gender, environment and locally available resources. Design Anthropology, therefore, is more than a mere description of the objects that are being produced. This type of research is primarily transformational and goes beyond documenting. The outcome can be written documents as well as crafts, drawings or sculptures, or even buildings or films. DA is founded on engagement and is always anthropology ‘with’ rather than ‘of’ the people.

It is in this domain that we propose a new type of design anthropology. We study (and re-make) indigenous footwear made by and with the craftspeople. The knowledge and ‘understanding together’ thus gained are used to isolate pertinent footwear features, which we then integrate in derivative footwear produced in different settings; from handmade in the artisan communities to handmade in small scale factories to semi-automated production. We look at how tools, techniques, and materials in their environment affect creativity. This type of DA is intrinsically a participating design anthropology. We follow the praxiological approach of Bourdieu (1981) towards knowledge theory. Within his praxiological perspective, Bourdieu states that all human and social scientific research is, in fact, a form of interaction and, therefore, deeply depends on the quality of the relationship between the researcher and the subjects of the re-

search (here, the artisans creating footwear). It is appropriate to engage the subjects as extensively as possible in that interaction and, thus, in the selection, interpretation, and evaluation of ‘facts’. In this way, the artisans under study become co-authors of the footwear made. The researcher and the artisans are equally close to the object of study and have the same interest in the skill of making, thus transcending the distance or even opposition between researcher and artisan. This approach moves from the view of an external observer, that is, a “God’s eye view” (Pinxten, 2010), and the intuition to first think and then make, towards a more holistic and participatory methodology. Under “God’s eye view” we humans look upon things, people, the earth as if we were able to take the point of view of the only outsider in the Western cultural tradition, that is, God. In contrast, in the ‘in habitat position’, a concept developed by Ingold (2013), thinking and making proceed in tandem as interacting formative processes.

2. Sustainable footwear on two levels

The first aspect of sustainable footwear concerns the environment. Since the 1960s global awareness and concern about the damage to the environment caused by people’s contemporary lifestyles has been increasing rapidly. Carson’s book (1962), the UN Stockholm Conference on the Human Environment (1972), the Brundtland report of 1987, and the Rio de Janeiro “Earth Summit” (1992) are all indications of this growing concern (Burns, 2012). The increasing scarcity of virgin material, the existing and forthcoming European producer responsibility directives, and ever increasing landfill charges necessitate that the appropriate end-of-life management and recycling of products are implemented in every manufacturing sector, including the shoe industry (Lee and Rahimifard, 2012). The footwear industry is a manufacturing sector that uti-

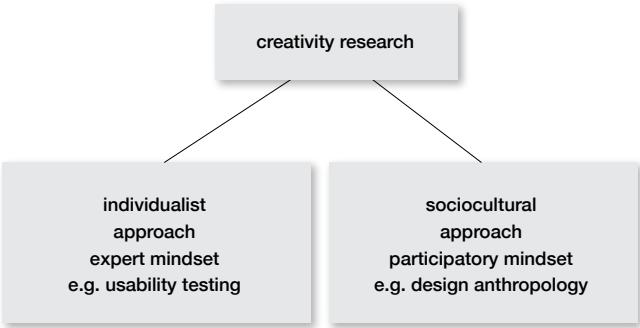
lizes a wide variety of materials and processes to produce a range of different products, from sandals to more specialised footwear, such as running shoes. The world-wide per capita consumption of footwear has increased considerably, from one pair of shoes per year for every person in the world in 1950 to almost 2.6 pairs of shoes in 2005. It is not surprising that this growth in shoe consumption has raised the environmental impact of the shoe industry. It is estimated that in the EU the amount of waste arising from postconsumer shoes could reach 1.2 million tons per year. The target of ‘Zero Waste to Landfill’ thus remains one of the major challenges of the 21st century for the footwear sector. This target is very ambitious as currently less than 5% of the 20 billion pairs of shoes produced worldwide every year are recycled or reused (SATRA, 2003). Different companies have presented initiatives for the development of environmental shoes, like the ECCO group, Nike, Timberland, and Camper (Herva, et al. 2011). In particular, footwear design is seen as a key factor in achieving significant improvements in material reclaim yield and purity. Lee and Rahimifard (2012) are currently working with producers worldwide on the implementation of ‘design for recycling’ within the footwear sector. They argue that such proactive approaches will give early adopters a significant competitive advantage when environmental legislation reaches the footwear sector (Lee & Rahimifard, 2012).

Next to the environmental sustainability of footwear we consider the impact of footwear on our feet and on our gait. Early humans have been running barefoot or wearing minimally supportive footwear such as moccasins or sandals (Trinkaus, 2005), whereas running shoes with cushioning to absorb shocks and stiletto’s without a wedge were not invented until the 1970s (Lieberman et al., 2010). Human feet evolved into their modern anatomy as barefoot structures for walking and running on natural – often hard

and rough – surfaces. Feet are the only parts of the body that touch the ground during gait and standing. As such, feet are key players in the deceleration during landing, in weight bearing, maintaining balance, and providing propulsion during locomotion. Most studies investigating the effects of footwear focused on foot deformities and reported that a habitually unshod foot in native populations was healthier than a habitually shod foot (Mafart, 2007; Zipfel and Berger, 2007). Already in 1905, Hoffman demonstrated irreversible damage to the forefoot due to wearing shoes. Hoffmann (1905) noticed that barefoot walkers universally have wider toe regions, a trend he also observed in classical sculptures. D’Aout et al. (2009) and Kandambande et al. (2006) have shown that unshod populations differ from habitually shod populations in their foot anatomy and function. D’Aout et al. (2009) found that barefoot walkers had wider feet and more equally distributed peak pressures.

One dimension that has been consistently under-researched is the effect on gait of walking with indigenous footwear. A study of Willems et al. (Prep. A) on the biomechanical implications of walking with Kolhapuri footwear (India) and Saami reindeer boots (Finland) shows that this type of footwear does not constrain the feet. Kolhapuri footwear and Saami boots alter foot biomechanics in a subtle way. These indigenous shoes might thus be considered “minimal footwear”. With a minimum of material both types of footwear offer a maximum of proprioception –that is, ‘the sense of one’s own body’– and protect at the same time against injuries and exposure to cold and heat. The benefit of running and walking barefoot has recently received much scientific attention (see, for instance, the special issue of Footwear Science (1), 2013) and media exposure. The barefoot trend has been embraced by runners and has led footwear manufacturers to develop shoes that aim to mimic the mechanics of barefoot locomotion. The ultimate goal of

Both disciplines of design and anthropology focus on transformation and on observing closely. The designer and the anthropologist become one. For the effect of this double position as a researcher we refer to chapter 5.



Kolhapuri footwear, buffalo chappal © David Willems



these ‘minimal shoes’ is to provide protection while still allowing the feet to move naturally. A proactive approach in the development of footwear can enhance walking and running in an injury free way.

3. Material and Method

In the next section we explain the procedure we followed to re-create indigenous footwear taking into account the two described perspectives, using the method of (participating) design anthropology.

3.1. Studying indigenous models: Action Research

Central to the (participating) design anthropology used in our study is that it is multi-sited, practice based, and conducted over an extended period of time. Between 2010 and 2014, we carried out fieldwork in Athani, India, and in Inari, Finland, during multiple stays of about 14 days. We worked with the Kolhapuri artisans of Toehold (<http://www.toeholdindia.com>), a not-for profit organisation promoting empowerment of rural women, with emphasis on social accountability in Athni, Karnataka, a central rural region of Southern India. In the North of Finland, in Inari, we worked with the Saami artisans at The Saami Education Institute, SOGSAKK (www.sogsakk.fi). The two indigenous types of footwear and the sites of production were selected for comparative purposes: nutukkaat, a winter footwear made from reindeer hide versus the Kolhapuri chappal a summer sandal using buffalo hide.

In both fields we collected data through participant observation, engagement through making, field notes, and interviews with the artisans, with consent of the interviewees. The results of the qualitative analysis were complimented with data gathered using quantitative methods of research. At the Ghent University, Department of Textiles, physical tests were executed on the indigenous footwear and the hides they were made

from (Jacobs, 2013; Peter, 2013). Biomechanical research on the difference of walking shod and barefoot on both types of indigenous footwear was conducted during field visits in 2010 and 2011. This biomechanical research is an important element of the design anthropology method used here because we see footwear as an extension of the feet. Initial results of this research reveal that the indigenous footwear can be considered minimal footwear *avant la lettre* (Willems et al., Prep. B).

3.2. In depth analysis: one reindeer, one pair of boots – one buffalo, fifteen chappals

The traditional Kolhapuri sandal –or chappal– features a leather sole, two side flaps (kanwali), an instep band, and a toe strap. The outsole, insole, upper, toe ring, and heel are sewn with leather threads from the tail of the buffalo. Kolhapuri refers to the city ‘Kolhapur’, but the geographical area of production is wider and also includes the town of Athani. Characteristic of the Kolhapuri chappal is the initial stiffness of the outsole and its differential response to wear: when wearing the chappal the leather becomes less stiff at the foot/ground/shoe contact while other parts retain their stiffness and ensure protection of the foot on the clayish rocky terrain. Stiffness of the outsoles was measured at the field setting (for worn sandals) and in a labo setting (both for new and worn sandals). The data reveal an average reduction of 38% in stiffness at the ball of the foot during the first day of wearing the chappal (that is, after 3000 steps). Additional aging of the chappals only reduces the stiffness by another 15% (see Annex 1). That is, most of the adaptation of the chappal to feet/ground interaction occurs during the first day of normal wear. The summer months in this region are extremely hot and humid, with temperatures reaching 40 °C. According to the artisans the vegetable tanned buffalo leather absorbs the heat and the moisture of the climate. Physical tests for water

vapour transmission support these anecdotal reports. Buffalo leather is more breathable than, the common synthetic alternatives for instance EVA, with mesh coverings, a material often used in footwear and known for its breathability (see Annex 2).

The Saami people mainly wear the nutukkaat during winter-time when the temperature is below –10 °C. The Saami, living in the northern parts of Norway, Sweden, Finland and northwestern Russia (Sápmi), are the only indigenous people in the EU to have their own language, culture, means of livelihood and identity. During interviews, subjects reported preferring these boots to factory-made boots especially at extremely low temperatures. The boot is entirely made from reindeer fur coming from the legs of the reindeer. Four legs make one boot. Inside the boot ‘kinkaheina’ (dried grass) is traditionally used for thermal insulation. We measured the thermal conductivity of the reindeer hide with and without grass. The thermal resistance also known as thermal insulance of the reindeer fur hide (measured in TOG) doubles when adding the grass (see Annex 3). This is consistent with the findings of Kuklane (1999) who proved that dry fibres and air between them are good insulators. The problem occurs when air in and between fibres contains moisture from inside or outside sources (for instance, melting snow). The physical test for water vapour transmission (see Annex 4) shows that the fur is less breathable than vegetable tanned leather, including the Kolhapuri leather. An additional test on water intrusion (see Annex 5) reveals that one can walk one day (6000 steps) in a wet environment before the hide shows signatures of water intrusion. But in reality the boots seldom get wet. As mentioned before the boots are used during colder weather (–10 to –30 °C or lower) when the water is frozen and water from the outside is generally not a problem. Interviews confirm that the footwear is not suitable for rainy days and temperatures around zero. Days with

changing weather and wet melting snow are the worst. The nutukkaat features a lifted nose, once used to connect with the ski. The sewing of the different pieces is traditionally done with the tendons of the reindeer. The opposite hair direction on the outsole provides a natural anti-slip. Determination of surface friction reveals that double force (N) is required to pull the fur over snow compared to concrete (see Annex 6 a). The boots perform best in their natural environment. The same can be said about the buffalo outsoles. The surface friction is highest on the clayish rocky terrain (see Annex 6 b). Woven laces are used to keep the snow out of the boot. The patterns and the colours of the laces refer to the different Saami communities, the gender, and the use of the boot, for instance, for festivity or for daily work.

Both types of footwear are entirely leather, manually made and do not have extra arch support or a heel path in or under the shoe. Each case using locally available resources for the hides (buffalo or reindeer) and for tanning (babul or willow bark). Both footwear are low weight (see, Annex 7) and become flexible after usage. In both, different parts of the animal are used for specific purposes at different stages of the making process. The tail is used as thread for hand stitching and the horns are used for polishing the leather. In both cases the use of material is optimized and wastage is recycled: the larger leftovers are used in between the layers of the heel parts and the smaller pieces are sold to farmers to fertilize the ground. Neither footwear uses any harmful adhesives. In both cases, the process is environmentally friendly and the material is considered comfortable for the feet. We isolated the features specific for each model. The features of the context and the features inherent to the footwear are grouped in the Table 1.

Table 1
Context and footwear related features

Context of the footwear	Kolhapuri	Nutukkaat
Made in	India, Karnataka	Sàpmi, the arctic circle
To walk on	clayish soil	snow, ice
Worn by	local/abroad adults and kids	local adults and kids
By an average temp. of	+25 °C	-25 °C
Worn during	all year round	winter
Features of the footwear	chappal, no back strap	closed boot
Material upper and sole	buffalo hide	reindeer fur legs
Different materials used	1 material, buffalo hide	1 material, reindeer fur legs
Amount of pattern pieces	7 pieces + thread	6 piece + loops and laces
Construction	handmade, hand-stitched	handmade, hand-stitched
Adhesives	none	none
Production time for 1 pair	1/2 day	3 days
Life span, durability	2 seasons	2 seasons
Leftovers	agriculture	shape of the full leg gets used
Use of last	/	/
Mass production	/	/
Amount of tools	9	4
Anti-slip	annex 6	annex 6
Thermal insulation	not applicable	annex 3
Water vapour permeability	see annex 2	see annex 4
Weight of one shoe	100 gr for measure 37	240 gr for measure 39
Thickness outsole	mean 9,6mm	mean 6,9mm

**3. Creating footwear:
collaboration with Vivobarefoot**

For the design of new footwear, we work with Vivobarefoot, a UK based shoe-design company that in 2004 became pioneers of the barefoot movement by launching the first minimal shoe with a patented, ultra thin puncture resistant sole. The company makes constructions specifically designed to let the foot work unrestrained as close to barefoot as possible. They make shoe solutions for different activities, terrains or environments –from high performance run-

ning shoes, off-road and trail running shoes, to work and kids shoes– and their vision for walking aligns with the multifaceted focus of our research. The design related aspects were elaborated in close collaboration with the artisans of both communities and with Vivobarefoot, whose founders joined us on field trips to Athani (January 2015) to make Kolhapuri inspired footwear and to Inari (February 2015) to make nutukkaat inspired boots. We note that all biomechanical analyses were done independently of Vivobarefoot, mainly at the University of Liverpool.

Nutukkaat, reindeer boot © David Willems
Saami lady chewing reindeer tendon for stitching the boot © Kristiaan D’Août



Through this collaboration, we aim at re-creating summer sandals and winter boots in four different production units, at sites chosen because of the scale of production and the specificity of tools, techniques, and materials used. We describe them below as three projects, with indigenous models serving as the overall inspiration. For the tools used to produce the different types of footwear we refer to ‘the rebirth of footwear’, the visual section of this thesis.

- **1 A: Kolhapuri footwear**
Athni (India- Karnataka): a chappal with strap over feet and a toering.
- **1B: Nutukkaat boot**
Inari (Finland – Saami): a winter boot featuring a tongue and a lace to keep the snow out.

• **1. The X-Indigenous project** re-creates footwear with the artisans of the indigenous communities with local materials and techniques both for their own market and abroad. Together with the artisans we create new handmade footwear inspired by indigenous footwear and barefoot gait respecting the natural anatomy of the feet. The models are hand-stitched and avoid glues and toxic materials.

• **2. The Hybrid project** re-creates the indigenous footwear in two small-scale factories near Porto, Portugal. The production is semi-industrial but still largely made by hand. The factories focus on environmental friendly ways of construction and handling of materials.

• **3. The 3D-Print project** re-creates the indigenous footwear with 3D printing (using the elastic filament Filaflex and low cost printers) at SLEM –Shoes, Leather, Education, Museum, an international innovation and education institute for footwear based in Waalwijk, the Netherlands. In Belgium we collaborate with RSPrint to re-produce the

models with Selective Laser Sintering (SLS). SLS is an additive manufacturing technique that uses a laser as the power source to sinter powdered material.

4. Future Footwear

In this section we describe the creation process of contemporary footwear prototypes based on the indigenous input in collaboration with Vivobarefoot (London, United Kingdom). Common factors¹ (or requirements) of the above-mentioned production projects are:

- 1. The style of the footwear keeps a close link to the indigenous footwear (that is, either the Kolhapuri chappal or the nutukkaat boot);
- 2. The last or shape of the new footwear reflects the barefoot gait as much as possible. The lasts of Vivobarefoot reflect the findings of the biomechanical measurements: the heel is more compact and round, the toe spring is lower, the last is asymmetric in shape with more room for toe function in comparison with conventional lasts (Willems et al., in preparation).
- 3. The footwear is created for a city environment, mainly to walk on concrete and on paved stones. Only the Saami reindeer boot –X-indigenous– is meant for extreme cold temperatures and outdoor natural environments.

All footwear images by David Willems

4.1 Summer urban, ‘hot’, Kolhapuri inspired footwear

X-Indigenous by Toehold Artisans (India)



The X-Indigenous model features a back strap and a leather buckle. In contrast to the original indigenous model the outsole is reversed. The advantage is that you see the epidermis and not the flesh side of the skin on the ‘kahn’, the sides. For anti-slip and improved abrasion resistance a TPU outsole is added underneath the outsole and the Vivobarefoot puncture resistant layer (Pro 5) is used in between in- and outsole for extra protection. The number of pieces needed is reduced from seven to four. However the pieces are bigger. All other features –for instance, weight and material– remain the same.

Hybrid by Limac (Portugal)



For this sample vegetable tanned cow belly leather was used because of local availability. The model is hand cut but stitched with a machine. A 3 mm TPU is added for abrasion resistance and PRO 5 for puncture resistance. All adhesives are water based. The sandal consists of five pattern pieces, including

the biodegradable webbing and gum buckle. The weight went up with 50 gr (150 gr for one sandal). The time to produce one pair is around four hours, which equals the indigenous production time. The capacity of the factory, however, is around 100 pairs per day if an order is placed. Since the Indigenous and X-Indigenous footwear is 100% hand-made they can never reach that production rate.

3D print with Filaflex (The Netherlands)



The design is 3D printed, in this case, with a Witbox –a low cost printer– using the software Cura. We used Filaflex, a thermoplastic elastomer, to print the model. The Filaflex is heated and prints when the nozzle (head of the printer) has a constant temperature of ca. 250 °C. To print the four pattern pieces an average of 15 and a half hour is needed for one shoe, size 37. The four pattern pieces can be printed separately, which may reduce the time (outsole=7 h for 57 g, strap over the arch=3 h for 27 g, insole and belt=5.35 h for 42 g). The indigenous weaving technique is used at the sides and a clicking system connects in- and outsole, thus offering anti-slip at the same time. Making the model out of one piece would increase the time needed to print, and the model would also need extra support under the straps. These printers inject melted filament on a plate (see ‘the rebirth of feet’ elsewhere in this thesis for images) and print their own support where needed (which takes extra time).

4.2 Winter urban, ‘cold’,
nutukkaat inspired footwear

Fur boot made in Inari (Finland) in
collaboration with a local artisan



Similar to the Kolhapuri chappal we reversed the outsole, bringing the fur inside the boot. This is not a new practice as different groups around the artic that work with fur reverse the hides for comfort in their footwear. Outsoles with hair are only functional on snow. The combination of the hide and thermal ‘grass’ offers optimal thermal comfort (for data, see Annex 3). We retained that feature but replaced the grass with a felt insole. For anti slip a 2mm rubber outsole –with inverted grip design which is ideal for cold dry city environments– is stitched onto the fur. Apart from the the outsole the full model is made from reindeer hide. In addition to a knife (the ‘jiekö’) to remove the flesh from the hide, a pair of scissors, and a needle, a stitching machine is desireable as it speeds up the work.

Felt boot made in a small-scale
factory in Portugal



Felt – also often used in the fur boots as nutukkaat – and vegetable tanned leather are combined in this model. The felt is treated with Nanofix (Europlasma) technology to give enhanced hydrophobic protection from the elements. For anti-slip a 3 mm rubber outsole (same as before) is stitched on the fur. A thin layer of pro 5 between in- and outsole offers everyday protection. The boot is handcut, but the stitching is done with a machine. The number of pattern pieces is similar to the Indigenous and the X-Indigenous, that is, six pieces. A previous paragraph noted that friction tests showed that pulling fur boots over snow requires twice as much force (N) than over concrete. When de-terminating the friction of the Vivobarefoot outsole using the same test we noted a better performance on concrete. This means that the outsole is better suited for urban envi-ronments than the fur outsole (see Annex 6).

3D LS at RSPrint (Belgium)



The final model is made with additive man-ufacturing. Additive manufacturing refers to a process in which digital 3D design data is used to build up a component in layers through deposition of material. When print-ing with STL one does not need support be-cause it is printed with powder around it. For several reasons we decided not to work with the low cost Witbox printer (and Filaflex) to produce the outsole. The first concerns the time needed to print. The calculated time for printing one outsole was ca. 15 hours when using the Witbox – in contrast, STL printers can print five pairs at a time in 8 to 10 hours. Second, Filaflex is not breathable, whereas

Table 1
Context and footwear related features

Context	Indigenous	X-Indigenous	Hybrid	3D SLEM
Made in	India, Karnataka	India, Karnataka	Portugal, Porto	Netherlands, Waalwijk
Soil	clayish soil	clayish, city	city	city
Worn by	adults	women	women	women
Temperature	+25 °C	+18 °C	+18 °C	+18 °C
Worn	all year round	summer	summer	summer
Features of the footwear	Kolhapuri	X-Indigenous	Hybrid	3D print
Style	chappal, no back strap	sandal, back strap	sandal, back strap	sandal back strap
Weight of one shoe	100gr /FP 37	100 gr / 37	150 gr /37	126 gr / 37
Material upper	buffalo	buffalo	cow belly leather	filaflex
Material sole	buffalo	buffalo	cow back leather	filaflex
Reinforcement	/	Pro 5	/	/
Buckle	/	full leather	gum buckle	/
Material items	1	2	4	1
Pattern pieces	7 + thread	4 + thread	4 + thread	4
Adhesives	/	/	water based	/
Production time	½ day	½ day	4 hours/100 day max	30 hours/ 1 pair
Life span	2 seasons	2 seasons	2 years min	/
Leftovers	minimal	minimal	recycling facility	/
Use of last	no	barefoot last	barefoot last	barefoot last
Amount of tools	9	9	10	3
Anti-slip	annex 6	annex 6	annex 6	/
Thermal comfort	annex 2	annex 2	/	/

with LS one can integrate air pipings en-hancing vapour transmission. Third, for this outsole we use TPU², which has higher durability. The equipment needed is, how-ever, larger in size and more expensive than Witbox.

Table 2
Context and footwear related features

Context	Indigenous	X-Indigenous	Hybrid	3D
Made in	Finland, Inari	Finland, Inari	Portugal, Porto	RSPrint, Belgium
Soil	snow	snow and city	city	city
Worn by	adults	adults	adults	adults
C°of	-10	-10	around 0	around 0
Worn	winter	winter	winter	winter
Features of the footwear	Kolhapuri	X-Indigenous	Hybrid	3D print
Style	boot	boot	boot	outsole
Weight of one shoe	240gr / 39	220gr / 37	200gr / 37	3D
Material upper	fur legs	fur legs	cow belly leather, felt,	TPU
Material sole	fur leg	fur leg & rubber	rubber	TPU
Reinforcement	/	Pro 5	/	/
Materials used	1	2	4	1
Pattern pieces	7 + thread	4 + thread	4 + thread	1
Adhesives	/	/	water based	/
Production time	3 days	3 days	1 day	/
Life span	2 seasons	2 season	2 years min	/
Leftovers	minimal	minimal	recycling facility	no
Use of last	no	barefoot last	barefoot last	barefoot last
Amount of tools	4	4	+10	4
Anti-slip	annex 6	annex 6	annex 6	/
Thermal comfort	annex 3	annex 3	annex 3	/

Discussion and
concluding remarks

In Future Footwear, the new designs are based on the features of the indigenous footwear that influence, on the one hand, the biomechanics of walking and, on the other hand, environmental sustainability. The challenge was to retain the biomechanical and environmental benefits of the traditional footwear in the design of modern city wear. In all cases, form follows the material and the way of producing (Ingold 2013), not the other way around, and intervention in form related aspects is thus minimal.

From a material point of view, we chose to work with light weight and thin materials to enhance barefoot feeling and proprioception. We also wanted the materials to be breathable, non-toxic and sourced close to the production unit. In the first production project, the X-Indigenous models, the same upper material is used as in the indigenous models, that is, vegetable tanned buffalo hide (as used in kolhapuri chappals) or vegetable tanned reindeer fur (used in nuttukaat). In the second, the Hybrid collection, natural felt was used along with vegetable tanned belly leather. On the outsole we added a natural rubber outsole to make the footwear appropriate for paved streets in urban environments. This had a minor effect on the weight of the footwear (see Table.). The third production project, 3D printing, uses a different process to create a fully formed object, built layer-by-layer. In contrast to the X-Indigenous and Hybrid (subtractive) production manufacturing, 3D printing is an additive process. Both in the indigenous communities (India, Finland) and in the Portuguese factories raw materials are cut from larger pieces and then reassembled to manufacture the final object. In the process a substantial amount of the (subtracted) material is wasted, with the chance of never finding its way back in an end product. The production of indigenous footwear does

not produce much waste, and left-overs –if any– are recycled in other products or used in agriculture as fertilizer. The Portuguese factories have their own recycling facilities, with small left-overs gathered and re-created into pressed leather, but zero waste, as in 3D printing is not achieved. According to Rifkin (2014), 3D printing, an additive process, uses approximately one tenth of the material used in subtracting manufacturing. We note, however, that as long as synthetic materials are used recycling of the end products of 3D printing is still a challenge. In the case of the Filaflex, for example, only about 10% of the materials used can be re-integrated in new filaments.

As mentioned in an earlier paragraph, the manufacturing of footwear –the supply of raw materials and the assembly of different components– make the footwear industry a polluting business. The indigenous shoes present a different way of producing. As in the production of indigenous footwear, the Future Footwear prototypes yield relatively few pieces. Of the projects considered, the Hybrid footwear in Portugal, which of the methods considered here involves the most conventional way of producing, yields the highest amount of materials used. The 3D Printing and Indigenous footwear processes have several aspects in common. First, in both only one type of material is used. Second, human involvement is low –in fact, one artisan can do the job. In 3D printing the ‘artisan’ designs software, and Rifkin (2014) refers to ‘infofacture’ rather than ‘manufacture’. The third and most striking similarity is the scale and scaling of the production. Low cost printers can (in principle) be set up anywhere, making it possible to create customized single products or small batches, made to order and at minimum cost. If one does not have access to a 3D printer, the growing number of fabrication laboratories can provide solutions. Furthermore, several companies have begun to offer online 3D printing services, which can be used to

create, share, and sell designs using additive manufacturing.

But 3D printing still faces several challenges. One concerns production time. As shown for the Kolhapuri 3D sandal, printing one sandal with elastomers using a low cost printer could take about 30 hours. Another concerns environmental sustainability. Even if the 3D printing movement is committed to sustainable production (McDonough and Braungart, 2012), which is compelling from the point of view of waste minimization, the energy cost is still high when the total supply chain (production and shipment of the printers and materials as well as the operation of the machines) is considered. With the cost (and negative environmental impact of the use of) of centralized fossil fuels constantly increasing, the need to harvest green electricity from renewable energy generated by local producer cooperatives has become more-and-more urgent. Finally, making 3D printing truly local requires that the feedstock used for creating the filaments is abundant and locally available. The materials for printing footwear are scarce and not yet fully recyclable. More interdisciplinary research between chemical engineering departments, anthropologists, and designers is needed on the use of natural fibers into filaments. Could, for example, the tendon used to stitch the reindeer boot inspire a new flexible filament?

In the three production types considered here, the results depend critically on the skill of the artisans. The embodied skill of working with material –the cobbler with leather or the potter with clay– can be passed on to the 3D designer working with the software. Tools lend themselves to manipulation. In India each artisan uses nine tools to hand-make the footwear. In Portugal many artisans are involved –the pattern maker, the leather cutter, the stitcher, the lasting, the finishing– each using specific tools to finalize the semi-industrial footwear. The

number of tools needed is lowest in the 3D printing. With computer, printer, and filament, a skilled 3D (software) designer can do the job. The emotional durability might be higher in products with natural material, such as leather, but for 3D printing this can be offset by the advantage of being able to customize your own footwear. The same applies to shape. All models were developed with a barefoot last. Compared to most footwear available on the market, which does not respect the shape and thus restricts the human foot (as shown in a previous chapter), our models do not compromise the human foot. The optimum is, of course, to create individualized wear for each singular and unique foot. This is implicit in the production of the indigenous footwear discussed here, and with modern technology it is possible to create individualized footwear based on a person’s foot scan. The software to do this already exists and along with further advances of 3D printing this offers a bright future for feet.

The comparison of features and production of indigenous models and the new prototypes allowed use to recognize and isolate common principles and processes, which –with adapted design– can guide the creation of footwear that will keep our feet and the environment balanced in locales around the globe. At the same time we recognize and appreciate that slow ways of producing demand a high degree of collaboration. This aspect of sustainable production contrasts (mass) production of more goods with less labour and at a lower cost. In indigenous manufacturing and with 3D printing, production is –to a large extent– directly linked with consumption. Cross-fertilization between indigenous skills and crafts and high-tech open-source 3D printing technology opens exciting new perspectives for footwear design and production. Further research is needed, however, to ensure a balance between sustainable design for feet and gait and for the environment, including

the search for solutions that are sustainable in view of social contracts in communities, net waste production, and energy use. Chapter 5 of this thesis offers a reflection of what this could mean for artisan communities. The design anthropological models described in this chapter are not intended to be finished products –indeed, they are still evolving in collaboration with the ‘artisans’ of the different production units– including the team members of Vivobarefoot and myself.

Acknowledgements

This experiment required close interaction with the artisans and a building of shared understanding and trust. Foremost, therefore, I want to thank the artisans in the communities. Second, I want to thank, Maria, the contact person in Portugal of Vivobarefoot and the artisans in the small scaled factories. Third, I am grateful for the help by René Medel, the industrial designer of SLEM (NL), and Jempi Wilsens and his team at RSPRINT (BE). A special thanks to Asher Clark for sharing his wonderful design skills, Joël Salamin for his skilled computer work, and Galahad Clark of Vivobarefoot for offering a full support during this ‘Future Footwear’ journey.

Notes

___ ¹ Colour of the footwear is mainly based on the softer nature colours of the two environments and the local materials.

___ ² Models in rubber-like are constructed from an off-white, very fine, granular powder. The result is a strong, high-flexible and durable material. The material is abrasive resistant. The technical name of the material is TPU 92A-1. TPU 92A -1 is a Thermoplastic Polyurethane derived from a Shore A 92.

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ANNEX

Physical tests on kolhapuri (buffalo chappals) and nutukkaat (reindeer boots)

Ghent University
Department of Textile - Hogent
Bachelor thesis fashion technology 2012-2013
Ida Jacobs and Marjolein Peter
Supervisors: dr. Carla Hertleer and Catherine Willems

1. Stiffness of the Kolhapuri outsoles at the metatarsophalangeal joint (MTPJ)

The stiffness of Kolhapuri sandals (also known as chappals) worn by subjects participating in the biomechanical research in Athni (n=36) were measured by pulling the outsole at the metatarsophalangeal joint (MTPJ) to angles of 15°, 30°, and 45°.

In addition, at the Department of Textiles at the Ghent University, four samples of new, ‘not worn’ chappals were measured using the same protocol as used in the field setting. Furthermore, these chappals were exposed to an aging process (through simulation of steps), and the stiffness (that is, the bending force, in Newton) was measured before and after this aging process.

At 15° the following results were obtained:

Condition	Sample 1	Sample 2	Sample 3	Sample 4
New	60,21 N	33,42 N	46,56 N	39,34 N
after 3000 steps	36,47 N (-39%)	20,93 N (-37%)	25,66 N (-45%)	26,76 N (-32%)
after 6000 steps	28,38 N (-22%)	16,99 N (-19%)	23,08 N (-10%)	24,58 N (-8%)

The laboratory results show an average reduction in bending force (N) by 38% for the four samples during the first part of the aging process (that is, after 3000 simulated steps). Additional aging (to 6000 steps) only reduced the force (N) with an extra of 15%.

2. Water vapour permeability of Kolhapuri leather

ISO 14268:2002 describes a method for determining the water vapour permeability of leather below 3,0 mm thickness and guides alternative methods of sample preparation. Water vapor permeability is the property that determines to what extent material is moisture proof or allows the transmission of water vapor. At the Ghent laboratory the standard used to determine the water vapour permeability of leather is ASTM E96-00 (Standard Test Methods for Water Vapor Transmission of Materials). Instead of standardized vapo cups, the Ghent lab uses plastic cups and silica gel. The process consists of three steps: first, silica gel, a desiccant, is put into a cup; second, a piece of leather is secured over the cup and placed in a controlled (humid) environment and, finally, after a period of time (for instance, 2,5 h) the cup is weighed to see how much water has been “pulled” into the cup through the leather. Assuming a linear process, the weight increase over a certain time interval then yields the flow rate in grams (of water) per hour.

Three samples of Kolhapuri leather:

	Sample 1 (2,46mm)	Sample 2 (2,8mm)	Sample 3 (2,07mm)
Additional weight per hour: interval 0-2,5 h	0,42 g/h or 1,03%	0,43 g/h or 0,99%	0,39 g/h or 0,97%
Additional weight per hour: interval 2.5-5.0 h	0,23 g/h or 0,57%	0,23 g/h or 0,54%	0,23 g/h or 0,57%
Additional weight per hour: interval 5.0-7.5 h	0,24 g/h or 0,59%	0,22 g/h or 0,51%	0,22 g/h or 0,54%
Total after 7,5 hour	2,23 g or 0,29 g/h	2,2 g or 0,35g/h	2,1 g or 0,28 g/h

Compared to Poron:

	Sample 1 (3 mm)
Additional weight per hour: interval 0-2,5 h	0,26 g/u or 0,63%
Additional weight per hour: interval 2.5-5.0 h	0,18 g/u or 0,45%
Additional weight per hour: interval 5.0-7.5 h	0,18 g/u or 0,43%
Total after 7,5 hours	1,55 g or 0.21g/h

3. Thermal insulation of reindeer fur

ISO 8302 describes the thermal properties of a material. The insulation of a material is rated in terms of thermal resistance, called the R-value (in m²K/W, W= Watt, K = Kelvin), which indicates the thermal resistance per unit thickness. The higher the R-value, the greater the hide’s insulating capacity. The R-value for given samples was measured using TECOSY: in this apparatus a sample is placed between two plates (at temperature T1 and T2, respectively) and the power needed to maintain a constant temperature contrast across the sample (in our case, ΔT=T1-T2=10 °C) is a measure of thermal resistance. Each sample was tested (three times) at different temperatures of the plates: a) T1 = 35 °C, T2 = 25 °C; b) T1 = 40 °C, T2 = 30 °C; c) T1 =45 °C, T2 = 35 °C, and the average of the three individual measurements was calculated. This was repeated for two different samples (1: reindeer fur of the leg; 2: the same sample but now with a layer of dry grass added), the average was calculated and used in the model. TOG (10xR) is a (British) measure of thermal resistance of a unit area, also known as thermal insulance, commonly used in the textile industry, and often seen quoted on, for example, duvets and carpet underlay.

Sample 1 reindeer leg fur (mean thickness 6,29 mm)	R (m2K/W)	TOG (10xR)
a) T1=35 °C and T2=25 °C	0,2421	2,42
b) T1=40 °C and T2=30 °C	0,2468	2,47
c) T1=45 °C and T2=35 °C	0,2468	2,68
Mean	0,2452	2,53
Sample 2 reindeer leg fur + grass (mean thickness 6,29mm + grass)	R - measure	TOG - measure
a) T1 35 °C and T2 25 °C	0,5236	5,24
b) T1 40 °C and T2 30 °C	0,5058	5,06
c) T1 45 °C and T2 35 °C	0,4621	4,62
Mean	0,4971	4,97

Note that the TOG nearly doubles when adding the grass, the ‘kinkaheina’.

4. Water vapour permeability of reindeer fur

For explanation of the measurements and definition of parameters, see Section 2 above.

	Reindeer fur (5,26mm)	Reindeer fur (6,9mm)	Non breathing material (3,13mm)
Additional weight per hour after 24 hours	0,016 g/h	0,024 g/u	0,002 g/u
Additional weight per hour after 14 days	0,014 g/h	0,015 g/u	0,004 g/u

5. WRONZ method ISO 8302 stepping in water / how water proof is reindeer?

For determination of water intrusion gait was simulated. After 6000 steps the fur shows signatures of water intrusion – remark: snow is not equal to stepping in water. Three times 500 heel steps are simulated in four boxes. Two boxes contain a wet mousse/sponge with red ink water, i.e. the wet situation and two boxes simulate the dry situation).

6. Slip properties of reindeer and buffalo hide

For determination of hide/substrate friction we use FIFA Test Method 08. In this method, a foot containing one type of material (in our case, reindeer fur hide, buffalo hide, or a vivo-barefoot outsole) moves (at a given speed) over a test specimen of another material (in our case, clayish earth, concrete, or snow), and the force required to do this is a measure of the friction between the materials. To ensure that the test foot (with skin) remains stable on the test plate (with a simulated substrate) and that the normal force is the same for all tests, mass was added to the foot for a total mass of 1,700 ± 50g. We measured the force required to pull the skin along the plate over a sliding distance of 100 mm at a speed of 500 ± 10mm/min. We repeated the measurement ten times, and the average forces (in Newton) are presented in the table below:

Reindeer fur boots: sample reindeer outsole.

On snow	Sample 1 Nutukkaat	Sample 2 Nutukkaat	Sample 3 Nutukkaat
Mean	16,840 N	23,856 N	9,081 N
On concrete	Nutukkaat		
Mean	9,134 N		
On metal plate with aceton	Nutukkaat		
Mean	6,282 N		

Kolhapuri, buffalo hide and Vivobarefoot outsole:

On grass	Kolhapuri 1	Kolhapuri 2	Vivobarefoot the one
Mean	5,817 N	5,817 N	11,036 N
On Clayish earth	Kolhapuri 1	Kolhapuri 2	Vivobarefoot the one
Mean	10,433 N	11,929 N	10,713 N
On concrete	Kolhapuri 1	Kolhapuri 2	Vivobarefoot the one
Mean	5,548 N	6,239 N	15,285 N

7. Weight in kg: balance with precision 0,001

ASTM D2346-00= Standard Test Method for Apparent Density of Leather ISO 1765:1986: Machine-made textile floor coverings -- Determination of thickness by using a digimatic indicator.

We measured thickness of the Kolhapuri sandals (n=36) at four locations using callipers. The medial midfoot region is least prone to wear and, therefore, its thickness reflects the raw material thickness best: it was 9.76 mm. The density of vegetable tanned buffalo leather is 0,641 g/cm3 (measured for a piece with thickness of 3,05mm), which is substantially less than that of natural rubber (about 0,930 g /cm3). The Kolhapuri footwear used in this study has an average mass of approximately 100 gr for European size 37 and approximately 150 gr for European size 42.

CONCLUSION

April 2015: After a 24 hour journey from Antwerp to Guangzhou –on my way to the Vivobarefoot China office to develop 3D knit for the ‘Future Footwear’ collection– the first I notice upon arrival is an overdose of products. Lots of cheap and ordinary products are displayed in the shops and shopping malls, one next to the other, including shoes. The streets breathe consumption, spending and waste. Once more I realize that design forms our environment and not always in a positive way.

At the onset of this thesis I posed the question if the study of indigenous footwear can guide sustainable production for feet and environment. Here I will summarise the findings (based on our fieldwork and quantitative analyses) described in the discussions of the individual chapters. We explored if indigenous footwear could serve as an example of a more balanced design between biomechanical and cultural functions. The two biomechanical studies (chapters 2 and 3) show that the types of footwear considered does not restrict the human foot –its natural form is respected and deformities do not occur. The indigenous footwear can be seen as ‘minimal footwear’ avant-la-lettre.

The design anthropological contributions of this thesis (chapters 1, 4, and 5) show that the reindeer fur boot keeps the feet warm in the coldest corners of the world and that the vegetable tanned buffalo hides keep the feet cool in the hottest places on earth. This footwear is important in everyday life and widely used even without a commercial marketing machine. The objects grow rather than being made. Production is low, in pace with need, and the transformation of the footwear over time is slow. The same can be said about the participating design anthropology proposed in this thesis. The industrial-, business-, and (perhaps) the academic world may not be interested in this long-term approach to making. My work shows, however, that designers can benefit from models that combine traditional craftsmanship and industrial and high-tech production, and I suggest that they should do so in view of increased footwear waste and landfill, global warming, and shortage of natural resources. To achieve a sustainable economy for all, we must further explore hybrid economies that combine conventional market places with collaborative aspects of new technologies and materials.

Chapter 6 compares different models for producing footwear. The models are linked with the tools needed for production and the treatment of the material. We concluded that in terms of choice of material and scale of production the indigenous footwear and the 3D printed models have a lot in common. (NB: I chose not to consider mass production because of challenges obtaining access to pertinent data and because of my interest in and vision for sustainable production.)

‘Future footwear’ stands between the past and the future. This transient and interactive back-and-forth movement is a source of imagination and creativity. ‘Future Footwear’ does not stop with the writing of this conclusion but will continue to evolve in collaborating with different communities to develop footwear that respects feet and environment.

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THE RE-BIRTH OF FOOTWEAR**