

DECLARATION

I declare that this dissertation is my own original work. It is being submitted for the degree of Master of Technology in the University of Johannesburg. It has not been submitted before for any award or degree or examination in any other University. All external sources drawn on have been duly acknowledged.

ANETTE LEONOR TELMO THOMPSON

DATE _____



ABSTRACT

Footwear is manufactured from foot forms or moulds known as “lasts”, based on certain measurements of the feet for whom the footwear is intended. Measurement or morphometric studies of the foot in other populations reveal differences due to genetic, ethnic and/or racial differences. Most last measurements used in the South African (SA) footwear industry are based on the British (UK) standard and assume an average fit for the entire population. No three dimensional (3-D) measurement data existed on the SA female foot that was statistically representative of all major ethnic groups of the female population. This was needed to test the current applicability of the UK standard, in light of previous findings that 80% of a random sample of South African women reported foot pathology ascribed to ill-fitting footwear. Further, this would address a suggestion that foot measurements might be non-linear in grading between small size individuals (size 3, 4 and 5) and large size individuals (size 8, 9 and 10).

This study essentially consists of three parts. First, a preliminary study undertook to find or create a suitable and affordable method of 3-D input, not only to obtain morphometric measurements but also to capture the topography of the weight bearing foot for future research and development of contoured foot beds for industry. Second, a comparison of specific measurements from a UK size 4 last and the corresponding foot measurements from a sampled population of size 4 foot length was performed, in order to determine what percentage of women would fit the footwear derived from such a last. Third, a comparison of mean values was carried out between data from participants of all sizes scaled down arithmetically to UK size 4 length, and data from actual size 4 participants, in order to explore whether the size 4, occurring as it does near the lower end of the size range, could still be representative of the proportional measurements for sizes 3 to 10. The mean values of this second scaled size 4 group were also compared to the UK size 4 last measurements.

The first part of the study utilized the resources of collaborative partners to locate 3-D hardware and software. Experimentation with compounds isolated a suitable impression material and platform designs were conceived to facilitate the data capture method developed. The invented method was awarded patent rights. The second part of the study

used the method developed from the preliminary study to conduct measurements. 3-D Laser scanning in combination with manual measurement for validation, by convenience sampling of each of 510 active women aged 21 to 69, of differing ethnic origins, in two major urban regions, yielded 13 foot measurements of each participant. Last measurements were captured by means of comparable laser scanning of a UK size 4 last. In the second part of the study, eight of the comparable measurements for size 4 feet and the last were compared for accuracy of fit. The third part of the study compared mean values between data from non size 4 participants scaled down arithmetically to UK size 4 length, and data from actual size 4 participants.

Part one of the study successfully developed and patented a new, portable, low-cost method which can be used to measure either a last or foot in 3-D for any footwear consumer group. Results of the metric study in part two indicate that four dimensions of the industry standard last do not fit the corresponding four dimensions of the average foot measured, namely forefoot girth, forefoot width, heel width and minor foot length (heel to fifth toe). More than 75.6% of participants from every ethnic group displayed tread girths larger than that of the last. These findings have serious implications since deficit fit in any of these four dimensions impacts negatively on foot health and function within the shoe. As such, results could not support the null hypothesis that the shoe fits the foot. Results in the third part of the study yielded similar mean values for measurement parameters between the two groups of data, indicating that the mean measurements for a size 4, even though it is placed near the lower end of the size range, can be representative of the mean scaleable measurements for sizes 3 to 10 but only for the length grade.

In conclusion, the study developed and patented a new method for a scientific process to record the weight bearing foot in 3-D. It produced the first national database of 3-D measurements of a female population on the African continent. Outcomes included new prototypes, innovation and technology transfer to industry. The study prompted the development of new footwear by the manufacturing industry partner, utilizing information gained from the study. The study has given impetus to continuing research on the African foot.

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Anette Leonor Telmo Thompson

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GLOSSARY

abduction. Motion away from the midline of the foot that occurs in the transverse plane around an axis that lies 90 degrees to the transverse plane and at the intersection of the coronal and sagittal planes.

adduction. Motion towards the midline of the foot that occurs in the transverse plane around an axis that lies 90 degrees to the transverse plane and at the intersection of the coronal and sagittal planes.

angle of gait. The angle which the feet assume relative to the body's line of progression during gait.

allowance. In adult shoes, the additional provision in size for foot stretch or expansion on weight bearing. Also the extra dimension allowed on the last for foot stretch or expansion on weight bearing. In fitting children's shoes, the extra length or width allowed for foot growth.

anthropometry. The branch of human science that deals with body measurements.

azimuth. An angle of rotation, used in conjunction with the angle of elevation, to define the apparent position of an object in space, relative to a specific observation point in 3-D orientation. See also *elevation*.

back cone. This is the portion of the cone section on the last between the "v" cut or thimble in the centre and the back end of the last. See also *back part*.

back curve. See *heel curve*.

back part. Term generally used in South African industry for the back cone of a last.

ball. In the foot, the ball comprises the heads of the five metatarsal bones and the surrounding tissue. On the shoe, the ball is the corresponding area or section. Along with the heel, the ball represents one of two primary weight bearing and tread sections of the foot and shoe.

ball girth. A measurement around the ball of the foot or last to determine shoe and last width and volume allowance inside the shoe. Also known as joint girth; a key measurement in last making.

base of gait. The closest width between the medial malleoli during the midstance phase of gait.

CAD Abbreviation for computer aided design.

CAM Abbreviation for computer aided manufacture.

CCD camera. A camera that uses a micro-manufactured silicon wafer (rather than a piece of film) to receive incoming light onto an array of linked (coupled) capacitors or photosites to capture picture elements or “pixels”. The silicon integrated circuit wafer or “chip” is called a charge-coupled device (CCD) and is used in high speed, high resolution applications such as digital photography, photometry, optical spectroscopy and astronomy.

clip. The tightness of shoe fit on the last around the topline; to fit tightly or snugly on the last; the gripping action of a shoe on the foot by virtue of its shaping and dimensions.

CMM Abbreviation for coordinate measuring machine.

cone. 1) The part of the last corresponding to the foot’s instep; important in shaping the shoe for proper fit. 2) The upper and centre portion of the last, divided into two sections, front and back cones. See also *front cone* and *back cone*.

coronal. The frontal plane of alignment of the body or parts thereof.

dorsal. Upper surface; in scanning a weight bearing foot, it is the visible surface from the edge of the surface on which the foot is resting, over the upper surface to the ankle region.

dorsiflexion. Motion towards the body that occurs in the sagittal plane around an axis that lies 90 degrees to the sagittal plane and at the intersection of the coronal and transverse planes.

elevation. An angle used, in conjunction with the azimuth angle, to define the position of an object in space relative to a specific observation point in 3-D orientation. See also *azimuth*.

euclidean That portion of geometry dealing with solids, as opposed to plane geometry. Solid geometry is concerned with polyhedra, spheres, three-dimensional solids, lines in three-space and planes.

eversion. Motion away from the midline of the body, occurring in the coronal plane around an axis that lies 90 degrees to the coronal plane and at the intersection of the transverse and sagittal planes.

fashion allowance. In adult shoes, the allowance of one part of the last for a fashion detail, for example, extra long toe box for elongated pointed toe escarpine styles.

feather edge. A very thin sole edge used mostly on women’s fashion shoes. The term also applies to some shoe components such as counters. See also *skived edge*.

feather line. 1) A reinforcement around the sole edge between sole and upper; 2) on the last, the line of small tacks placed around the rim where upper and bottom meet on the finished shoe.

flare. To curve or contour, as with an inflare or outflare last. Used either as a styling feature or for therapeutic shoe design for a foot correction.

flexion. The bend action of the foot across the ball, or of a shoe or outsole across the ball and vamp; the degree of the flex action is an indication of the functional normalcy of the foot or the walking ease of the shoe.

front cone. The portion of the last cone between the V-cut or thimble in the centre and the vamp point on the top surface behind the toes. See also *toe part* and *cone*.

gait. Term used to describe the manner of human locomotion.

gait cycle. Sequence of movement phases that make up two sequential steps in human locomotion. Two main phases are “Stance” (in which the foot is planted on the support surface and takes weight) and “Swing” (in which the foot is non weight bearing and is moving forward towards the next heel strike) The gait cycle begins when one foot contacts the ground and ends when that foot contacts the ground again. Thus, each cycle begins at initial contact with a stance phase and proceeds through a swing phase until the cycle ends with the limb's next initial contact. Stance phase accounts for approximately 60 percent, and swing phase for approximately 40 percent, of a single gait cycle.

Each gait cycle includes two periods when both feet are on the ground. The first period of double limb support begins at initial contact, and lasts for the first 10 to 12 percent of the cycle. The second period of double limb support occurs in the final 10 to 12 percent of stance phase. As the stance limb prepares to leave the ground, the opposite limb contacts the ground and accepts the body's weight. The two periods of double limb support account for 20 to 24 percent of the gait cycle's total duration.

girth. Any of several circumference measurements taken on the last, such as around the ball, waist and instep; or similar measurements on the foot. Girth allowance on the last differs depending on needs, e.g. closed tab boot has a wider girth allowance than an open tab boot.

GRF Abbreviation for ground reaction force; see *ground reaction force*.

ground reaction force. A force equal in magnitude and opposite in direction to the force that the body exerts on the supporting surface through the foot.

hallux. Plural *halluces*. Anatomical name for the big toe.

heel angle. The down slant or angle of the heel seat on which the heel of the foot rests.

heel. The raised component under the rear of the shoe, consisting of any of a wide variety of shapes, heights, styles and materials. The raised heel has origins dating back at least

3000 years and was used in a utility manner to prevent the feet of horsemen from slipping out of the stirrup, and also to increase the wearer's stature and status. The modern high heel (two or more inches in height) dates back to the 16th century and has evolved into a primary fashion feature in a shoe for women.

heel curve. The back curve of a shoe from heel seat to the top rim to conform to the back curve of the foot. The curve shape varies in accord with heel height, style, or construction of the shoe or boot. The heel curve must be precise to avoid shoe slippage or biting at the heel. Also known as *back curve*.

heel pitch. The vertical slant or angle of the heel at the rear from heel seat to foot; not to be confused with the *heel angle*.

heel height. The height, floor to shank, measured at the heel breast. Heel height is measured in increments of one 8th of an inch. Hence an 8/8 heel is one inch, a 20/8 is 2 and a half inches, and so on.

heel seat. The flat or slightly cupped section of the shoe on which the foot's heel rests; also the section of the shoe to which the heel is attached.

heel seat width. On the last, the width across the heel seat, rim to rim at the widest points; the greatest width across the heel seat on a line perpendicular to the centre line from the heel point. Also described as *heel stick width*.

instep. The top inner portion of the foot at its crest, formed by the articulations of the bases of the first three metatarsal bones with the navicular bone and the first two cuneiform bones.

instep girth. The circumference around the foot at the instep, an important last measurement.

inversion. Motion towards the midline of the body, occurring in the coronal plane around an axis that lies 90 degrees to the coronal plane and at the intersection of the transverse and sagittal planes.

joint girth. See *ball girth*.

last. The plastic, metal or wooden foot shaped form over which the shoe is made to conform to the prescribed shape and size of the shoe. Also used as a verb to describe the process or action of shaping the shoe to the last.

lasting. The operations in the factory involved in forming all parts of the shoe to the last, including such special operations as toe lasting, side lasting, heel seat lasting.

last measurements. 1) The numerous measurements taken on all parts of the last to determine proper size and fit of the shoe, and also proper tread and shoe performance. 2) The standard measurements for sizes and widths for each footwear category such as infants', children's, youths, misses, men's and women's shoes. 3) The standard measurements designated for the girth of ball, waist, and instep for given shoe sizes relative to the type of footwear.

length. The length measurement of the foot from the back of the heel to the tip of the longest toe; also the length of the shoe from heel to toe tip but not including the shoe's sole.

length allowance. Additional length added to the last to allow for fashion or an extended toe recede slope; allowance of size for foot stretch or expansion on weight bearing.

osseous. Bone or of bone.

pes cavus. Medical umbrella term for a foot with a high arch or humped instep, irrespective of aetiology.

pes planus. Medical umbrella term for a flat foot with a lowered and flattened medial longitudinal arch, irrespective of aetiology.

pitch. Also known as last pitch or heel pitch.

plantar. Under surface; in scanning a weight bearing foot, it is the surface in contact with the load bearing surface, not visible while the foot is weight bearing.

plantarflexion. Motion away from the body that occurs in the sagittal plane around an axis that lies 90 degrees to the sagittal plane and at the intersection of the coronal and transverse planes.

podometry. The branch of human science that deals with measurement of the foot.

pronation. A triplanar movement along the long axis of the foot consisting of eversion, abduction and dorsiflexion.

radial basis functions. A mathematical concept to interpolate polygonal surfaces into smoothed contiguous surfaces.

rapid prototyping. An additive manufacturing process that creates a model of an object directly from a CAD model by building it in layers, usually of resinous material.

RBF. See *radial basis functions*.

recede. The part of the closed shoe toe shape that extends beyond the end of the toe of the foot, often slanted forward and downward or tapered.

relaxed calcaneal stance position. Term used in biomechanics to describe the angular relationship between the calcaneus and a perpendicular to the ground on weight bearing, while standing relaxed in the angle and base of gait; angular degrees range from varus to valgus.

retinacula. Tough fascial bands, as in the ankle region; these hold tendons in position.

roll. Term used in 3-D to denote an orientation less than or greater than the horizontal.

seat. See *heel seat*.

size grading. The increments of size progression in shoe sizes or widths. In the metric system, the size progression is in centimeters. In the American sizing system, length is measured in 1/6 inch per half size and 1/3 inch per full size; or 1/4 inch for each width change.

SMME. Abbreviation for small, medium and micro enterprises

sock. Footwear manufacturing term for inner sole of the shoe; also an item of hosiery.

stick length. Length derived from using a stick measure; the overall length of the last measured with a last size stick.

STL. Abbreviation for Standard Tessellation Language, computer code in a polygonal model format that is used for rapid prototyping.

supination. A triplanar movement along the long axis of the foot consisting of inversion, adduction and plantarflexion.

swing. The curvature of the outer rim of the outsole, or on a last.

synovial sheath. Fibrous sac lined with a smooth membrane, producing a viscous lubricant known as synovial fluid, enclosing a tendon in the foot.

3-D Abbreviation for three dimension or three dimensional.

toe part. Term commonly used in South Africa for the front cone of a last.

toe spring. The elevation of the under surface of the sole at the toe so as to give the sole a slight rocker effect for an easier step. The amount of toe spring (built into the last) depends on shoe style, sole thickness and heel height.

topline. The top rim of the shoe's upper.

topline clip. The amount of tightness of shoe fit on the last around the topline; to fit tightly or snugly on the last.

tread. 1. The widest part across the ball of the foot on the last; 2. the area of the sole of the shoe that comes into contact with the ground for walking.

upper. All the parts or sections (vamp, quarters, linings, etc.) above the sole of the shoe that are stitched or otherwise joined together to become a unit, and then attached to the insole and outsole.

varus. Varus of the foot or part of the foot means a fixation of the part in the position it would assume if inverted. It is a frontal plane fixation in which the plantar surface of the foot is directed towards the midline of the body.

valgus. Valgus of the foot or part of the foot means a fixation of the part in a position it would assume if everted. It is a frontal plane fixation in which the plantar surface of the foot is directed away from the midline of the body.



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