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4 RESULTS

4.1 Part one: development of a 3-D method

Part one of this study resulted in an extraordinary approach to develop a technological method that previously did not exist, either in academia or industry. It successfully developed a technique that captured accurate (within 1 mm) digital foot measurements but also captured the natural foot contours under a weight bearing foot in 3-D (Figure 4.1).

This part of the study developed research skills in communicating podiatric principles to non-podiatric disciplines. The development of the method resulted in the first South African podiatrist trained in 3-D laser scanning of the foot. It also developed the problem-solving ability of the researcher while successfully interacting with collaborators on three continents. Part one of the study successfully interacted and recommended development directions through twenty six software version modifications of beta testing, before arriving at a final product that not only fulfilled but exceeded requirements. It thus maximized the requirement of the study to enable industry to pursue future developments in contoured foot bed technology.

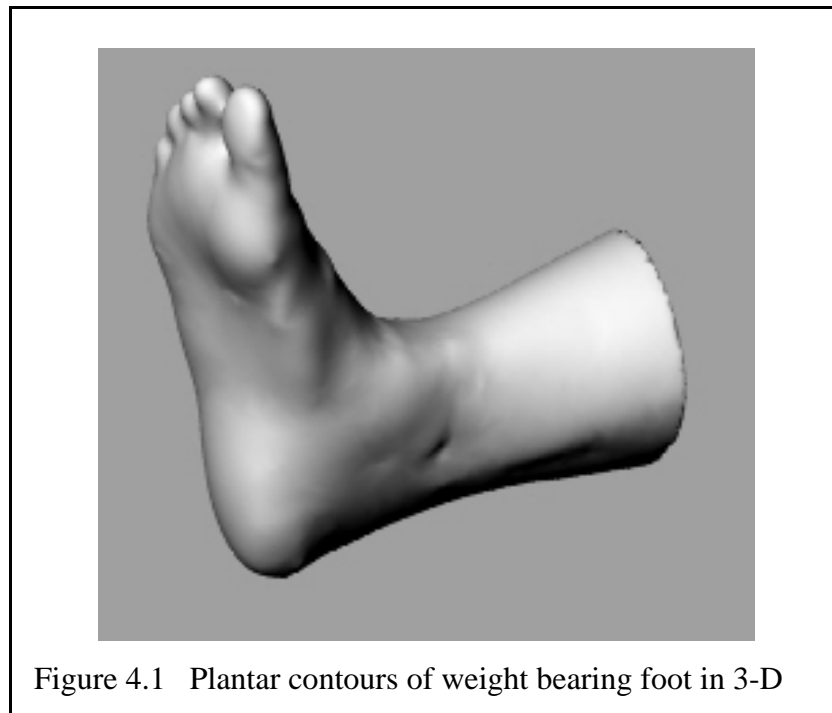
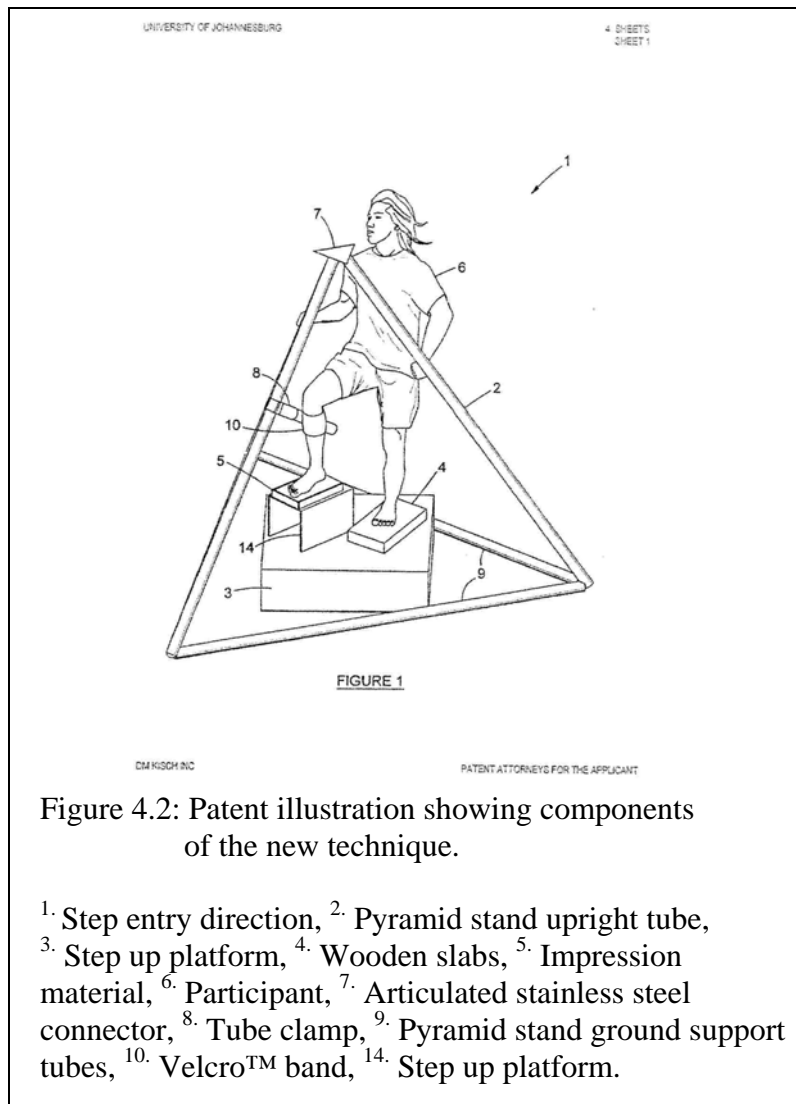


Figure 4.1 Plantar contours of weight bearing foot in 3-D

4.1.1 Patent of 3-D method

Since the method that resulted from part one of the study was a new invention, it was selected for patent. The intellectual property rights to the “method of data input of the complete 3-D surface of a human foot in weight bearing and partial weight bearing positions utilizing a laser scanner and impression forming material” developed in part one of the study were licensed to the University of Johannesburg.

South African patent 2006/04167 was registered by the University of Johannesburg (Appendix XXII) to protect the patent rights and enable the commercialization of the intellectual property (the method) to other prospective users for morphometric studies of the foot (Figure 4.2).



4.2 Part two: Multi-ethnic 3-D metric study

A total of five hundred and ten women's feet were measured by the method described in 3.4, resulting in five hundred and ten Handheld Laser Scan (HLS) format data files. The selected last, "Ingrid size 4" was also measured by the method described in 3.4.9.2, which also produced an HLS format data file.

The post scanning processing sequence (3.2.8.2 to 3.2.10) yielded Comma Separated Value (CSV) files that contained the *x*, *y* and *z* co-ordinates (in 3-D space) corresponding to the landmark points, from which digitally derived measurements were obtained.

The derived foot measurements were then compared to the derived last measurements in order to answer the research question.

4.2.1 Participant demographics

Data was collected as planned from urban residents in Johannesburg and Durban. Table 4.1 shows the source of participants.

n	Organization	Participant description	Province
132	University of Johannesburg Doornfontein campus	Administrative workers, lecturers, students	Gauteng
76	University of Johannesburg Kingsway campus	Administrative workers, lecturers, students	Gauteng
25	Rhema Church, Randburg	Church members	Gauteng
20	SA Broadcasting Corp.	Administrative workers, Announcers	Gauteng
45	SA Airways, Kempton Park	Air hostesses	Gauteng
30	Michelle Footwear	Administrative workers	Kwazulu Natal
105	University of Kwazulu Natal, Westville campus	Administrative workers, Lecturers, Students	Kwazulu Natal
77	John Dunn House, Wentworth community	Administrative workers, Retirees	Kwazulu Natal
510	Total		

4.2.2 Sample bias and stratification

With the exception of one person at the University of Kwazulu Natal, no prospective participant refused to participate on being asked either in person or telephonically to volunteer.

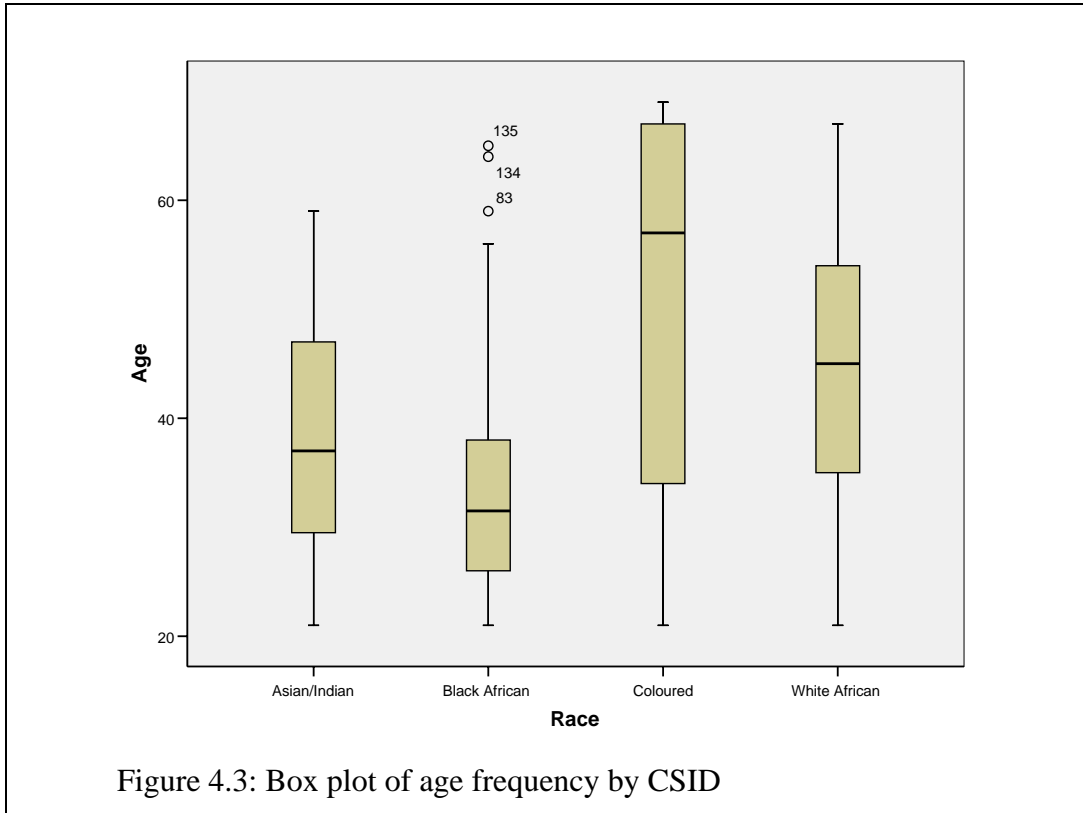
Although participants in the study represented subset samples of two major urban areas whose populations contain members of all home language groups, the sample was found to contain no participants from the Ndebele or Venda tribes (Table 4.2). This occurred in spite of stratifying or dividing the sampled groups into sub lists according to the qualifying traits of (a) working women able to afford leather shoes or (b) active retired women able to afford leather shoes, from the types of organizations as indicated in 3.3.1.3.

Table 4.2: Home languages represented in the study. * Other indicates bilingual home; ** Indicates no participants			
Language	Language Abbreviation	Frequency	Percentage
Afrikaans	AFR	89	19.6
English	ENG	245	54.1
IsiNdebele**	NDE	0	0
Sepedi	PED	12	2.6
Sesotho	SOT	16	3.5
Siswati	SWA	4	0.9
Xitsonga	TSO	5	1.1
Setswana	TSW	23	5.1
Tshivenda**	VEN	0	0
IsiXhosa	XHO	13	2.9
IsiZulu	ZUL	42	9.3
Other	OTH	4	0.8
	Total	453	100.0

After discarded data was subtracted from the total data, and when the remaining data was grouped into the planned age intervals, the frequency distribution between age group intervals approximated the planned frequency distribution as shown in Table 4.3.

Table 4.3: Age group frequencies			
Age group intervals	Percentage planned	Actual Frequency	Actual Percentage Sampled
21 – 29 years	20	107	23.6
30 – 39 years	30	124	27.4
40 – 49 years	20	94	20.7
50 – 59 years	15	70	15.5
60 – 69 years	15	58	12.8
TOTAL	100	453	100.0

Although there was adequate frequency among the age intervals for the total sample (see Table 4.3), the age distribution among the four different ethnic groups was disparate (Figure 4.3). Asian/Indians and Black Africans constituted a much younger sample, (mean age 38.27 and 32.98 years respectively) followed by White Africans (mean age 51.45 years). The Coloured ethnic group represented the widest range of ages (21 to 69 years) and had the strongest representation of the age 60 to 69 group (Figure 4.3).



As described in 3.3.1.1, the study planned to measure at least 100 participants from each ethnic group. Table 4.4 reflects the actual figures for ethnic groups for which viable data was measured in the study.

Table 4.4: Cultural and self-identification (CSID) of participants			
CSID		Frequency	Percentage
ASI	Asian/Indian	111	24.5
BAF	Black African	122	26.9
COL	Coloured	102	22.5
WAF	White African	118	26.0
Total		453	100.0

As far as stature was concerned (Figure 4.4), White Africans were the tallest group sampled (mean 1.67 metres), followed by Black Africans (mean 1.62 metres). The Coloured group and Black Africans displayed the widest range of height (1.42 metres to 1.80 metres), while the maximum height sampled in the Asian/Indian group was 1.75 metres.

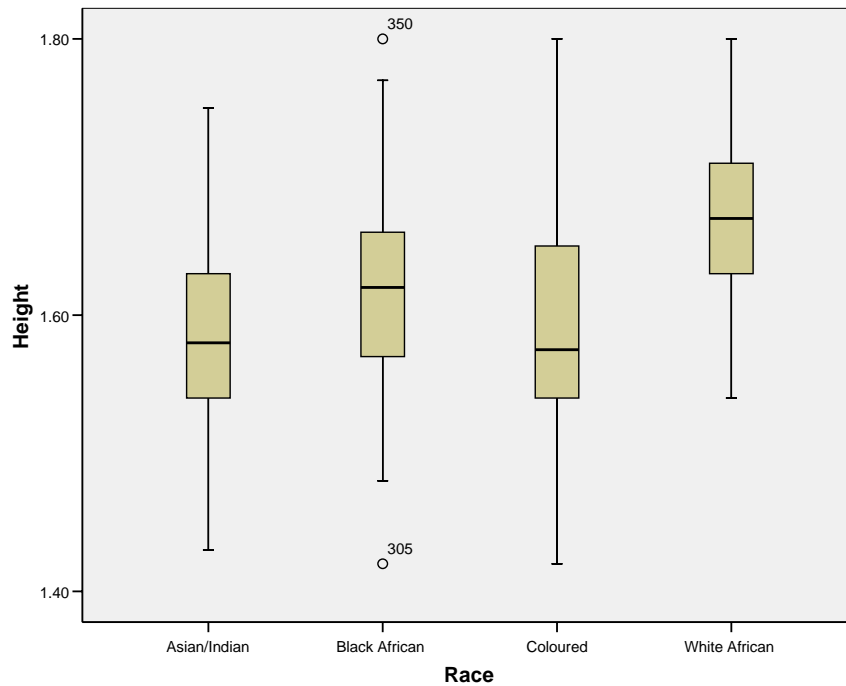


Figure 4.4: Box plot of height frequency by CSID

4.2.3 Analysis on group representing actual size 4

Within the group of 453 viable data records, 129 records were found in which the foot length was between 228mm and 237mm, considered by industry to be feet that would fit a “UK size 4”. These 129 records constituted the first group whose measurements were analyzed and then compared to the “Ingrid” last.

4.2.3.1 Descriptives

In Table 4.5, the measures of central tendency for the size 4 group (N = 129) are summarized. The mean or arithmetic averages for age, height and mass display positive skewness, meaning that their means are greater in value than their medians. This is caused when data has a number of high scores or values near the maximum range. The opposite is true for negative skewness (Healey, 1993:72). Mild negative skewness is present in the measurements for Major foot length, Minor foot length, Arch height, Heel seat width and Tape forefoot girth, indicating that the data has a number of values near the minimum range.

Table 4.5: Summary of descriptive statistics for size 4 group							
	N	Minimum	Maximum	Mean	Standard Deviation	Skewness	Kurtosis
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic
Age	129	21	69	40.40	13.361	.527	-.708
Height	129	1.45	1.80	1.5917	.05741	.233	.268
Mass	129	34.7	104.7	65.233	12.3350	.702	.704
BMI	129	13	46	25.88	5.487	.871	1.397
A: Major foot length	129	228	237	232.72	2.775	-.220	-1.120
B: Minor foot length	129	182	206	194.72	4.550	-.067	-.133
C: Toe height	129	17	32	22.57	2.397	.986	1.752
D: Tread width	129	78	103	90.50	4.559	.128	-.029
E: MPJ5 *	129	56	81	67.67	5.099	-.090	-.160
F: Navicular	129	25	58	39.37	7.739	.296	-.505

Table 4.5: Summary of descriptive statistics for size 4 group							
height							
G: Arch height	129	12	35	23.69	4.924	-.117	-.369
H: Heel seat width	129	47	73	62.62	4.384	-.055	.492
I: Heel*	129	0	24	5.22	3.412	1.911	7.310
J: Heel ball 1	129	163	183	173.26	4.127	.071	-.318
K: Heel ball 5	129	144	168	156.49	4.768	.116	-.148
L: Tape forefoot girth	129	180	275	227.00	12.321	-.036	2.294
Valid N	129						

* Note: E and I are positional references and do not constitute foot measurements.

In order to provide more information regarding those variables that displayed skewness, degree of kurtosis have also been shown in Table 4.5. Kurtosis is the degree of “peakedness” of a distribution. A distribution with a high peak (kurtosis value is >0) is called leptokurtic, indicating a high number of closely distributed values. A distribution with a flat topped curve (kurtosis value is < 0) is called platykurtic and indicates a wide range of values (Kenney & Keeping, 1962:102).

In this way, for example, when considering the slight negative skewness of Tape Forefoot Girth (L) which reveals that this variable has a number of values near the minimum, the leptokurtic value indicates a distribution with a high peak of closely distributed values about the mean. This occurs similarly with the value for the variable of Heel Seat Width.

The kurtotic values for the variables Heel to ball 1 and Heel to ball 5 are platykurtic, thus revealing a wide range of values and this has implications for footwear “ball of the foot” flex ranges that will be discussed in 5.3.1. Similarly, the kurtotic values for the variables for Navicular Height, Arch Height, Tread Width and Minor Foot Length are platykurtic which indicate a wide range of values that are important to shoe fit. These will be discussed in 5.3.

Normality testing was performed by means of the one-sample Kolmogorov-Smirnov test as per table 4.6.

Table 4.6: Normality overall for the total sample ($N = 453$)								
	N	Normal Parameters(a,b)		Most Extreme Differences			Kolmogorov-Smirnov Z	Asymp. Sig. (2-tailed)
		Mean	Standard Deviation	Absolute	Positive	Negative		
Age	453	41.28	13.860	.096	.096	-.072	2.041	.000
Height	453	1.6172	.07605	.054	.054	-.051	1.159	.136
Mass	453	70.147	15.7841	.072	.072	-.046	1.535	.018
BMI	453	26.87	5.930	.091	.091	-.061	1.932	.001
A: Major foot length	453	239.74	12.327	.045	.045	-.020	.953	.324
B: Minor foot length	453	200.55	10.478	.036	.036	-.024	.775	.585
C: Toe height	453	22.84	2.348	.099	.099	-.071	2.101	.000
D: Tread width	453	92.84	6.091	.060	.060	-.041	1.280	.075
E: MPJ5 height	453	68.86	5.833	.052	.052	-.045	1.116	.166
F: Navicular height	453	39.39	7.308	.044	.039	-.044	.929	.353
G: Arch height	453	24.35	4.848	.065	.038	-.065	1.391	.042
H: Heel seat width	453	64.23	5.207	.064	.064	-.041	1.359	.050
I: Heel height	453	5.08	3.519	.145	.145	-.074	3.087	.000
J: Heel ball 1	453	178.05	9.205	.037	.037	-.028	.792	.557
K: Heel ball 5	453	160.86	9.277	.041	.041	-.026	.863	.446
L: Tape forefoot girth	453	232.92	14.493	.046	.046	-.032	.970	.303
a Test distribution is Normal.								
b Calculated from data.								

As anticipated in 3.3.3.2.4, the Central Limit Theorem explains why this test distribution is normal. Because the sample size is greater than 100, it can be assumed that the sampling distribution is normal with a mean equal to the population mean (Healey, 1993:150).

4.2.3.2 Frequency distributions

Comparison to the last took the form of a frequency, counting how many and what percentage of each foot measurement fitted into the last parameter for that measurement. This was done for the overall group of size 4 ($N = 129$) as well as by each ethnic group (ASI: Asian, WAF: White African, BAF: Black African and COL: Coloured) as described in 3.3.3.2.2. The results are provided per foot measurement variable.

4.2.3.2.1 Major foot length

Within the sample of 129 actual size 4 participants, it was expected that the mean would be the industry standard of 234mm. The mean for this variable in this sample was 233mm.

4.2.3.2.2 Minor foot length

Comparison to this measurement indicated whether the tip of the fifth toe would fit footwear formed on the “Ingrid” last. More than half of the group (55.8%) displayed a fifth toe length that would not fit the “Ingrid” last (Table 4.7)

Table 4.7: Minor foot length overall frequency			
		Frequency	Percent
Valid	Less than or equal to last measurement	57	44.2
	Greater than last measurement	72	55.8
	Total	129	100.0

When split by ethnic group this lack of fit was present in all ethnic groups, but shown most strongly in White Africans (80%), followed by Black Africans (53.6%), Asians (50%) and Coloured (47.4%), as per Table 4.8.

Table 4.8: Minor foot length frequency by CSID			
CSID		Frequency	Percent
ASI	Less than or equal to last measurement	19	50.0
	Greater than last measurement	19	50.0
	Total	38	100.0
BAF	Less than or equal to last measurement	13	46.4
	Greater than last measurement	15	53.6
	Total	28	100.0
COL	Less than or equal to last measurement	20	52.6
	Greater than last measurement	18	47.4
	Total	38	100.0
WAF	Less than or equal to last measurement	5	20.0
	Greater than last measurement	20	80.0
	Total	25	100.0

4.2.3.2.3 Toe height

Comparison to this measurement indicated whether the height or thickness of the hallux would fit footwear formed on the “Ingrid” last. Over two fifths of the group (42.6%) displayed a fifth toe length that would not fit the “Ingrid” last (Table 4.9)

Table 4.9: Toe height overall frequency		
	Frequency	Percent
Less than or equal to last measurement	74	57.4
Greater than last measurement	55	42.6
Total	129	100.0

When split further by ethnic group, this lack of fit was present in all ethnic groups but shown most strongly in Black Africans (57.1%), followed by Coloureds (47.4%), Asians (42.1%) and White Africans (20%) as per Table 4.10.

Table 4.10: Toe height frequency by CSID			
CSID		Frequency	Percent
ASI	Less than or equal to last measurement	22	57.9
	Greater than last measurement	16	42.1
	Total	38	100.0
BAF	Less than or equal to last measurement	12	42.9
	Greater than last measurement	16	57.1
	Total	28	100.0
COL	Less than or equal to last measurement	20	52.6
	Greater than last measurement	18	47.4
	Total	38	100.0
WAF	Less than or equal to last measurement	20	80.0
	Greater than last measurement	5	20.0
	Total	25	100.0

4.2.3.2.4 Tread width

Comparison to this measurement indicated whether the width of the forefoot would fit footwear formed on the “Ingrid” Last. Almost the entire group (96%) displayed a wider tread width that would not fit the “Ingrid” last (Table 4.11)

Table 4.11: Tread width overall frequency		
	Frequency	Percent
Less than or equal to last measurement	5	3.9
Greater than last measurement	124	96.1
Total	129	100.0

When split further by ethnic group, this lack of forefoot fit was present in all ethnic groups but shown most strongly in Coloureds and Asians (100%), followed by White Africans (92%), and Black Africans (89.3%) as per Table 4.12.

Table 4.12: Tread width frequency by CSID			
CSID		Frequency	Percent
ASI	Greater than last measurement	38	100.0
BAF	Less than or equal to last measurement	3	10.7
	Greater than last measurement	25	89.3
	Total	28	100.0
COL	Greater than last measurement	38	100.0
WAF	Less than or equal to last measurement	2	8.0
	Greater than last measurement	23	92.0
	Total	25	100.0

4.2.3.2.5 Heel seat width

A tolerance of 10mm was allowed on this measurement parameter, to allow for heel “clip” or grip of the footwear against the heel. Comparison to this measurement indicated whether the width of the heel would fit footwear formed on the “Ingrid” Last. By far the majority of the group (96%) displayed a heel seat width that would not fit the “Ingrid” last (Table 4.13)

Table 4.13: Heel seat width overall frequency		
	Frequency	Percent
Fits last measurement with 10mm margin either side	1	.8
More than 10mm larger than last measurement	128	99.2
Total	129	100.0

When split further by ethnic group, this lack of heel fit was present in all ethnic groups (100% in Black Africans, Coloureds and White Africans, followed by 97.4% in Asians) as per Table 4.14.

Table 4.14: Heel seat width frequency by CSID			
CSID		Frequency	Percent
ASI	Fits last measurement with 10mm margin either side	1	2.6
	More than 10mm larger than last measurement	37	97.4
	Total	38	100.0
BAF	More than 10mm larger than last measurement	28	100.0
COL	More than 10mm larger than last measurement	38	100.0
WAF	More than 10mm larger than last measurement	25	100.0

4.2.3.2.6 Heel to Ball 1

Comparison to this measurement indicated whether the first metatarsophalangeal joint would line up with the inner flex position of footwear formed on the “Ingrid” Last. A tolerance of 2mm was allowed. Less than a quarter of the group (21.7%) displayed a heel to ball 1 length that would fit the “Ingrid” last (Table 4.15).

Table 4.15: Heel to ball 1 frequency overall		
	Frequency	Percent
More than 2mm smaller than last measurement	98	76.0
Fits last measurement with 2mm margin either side	28	21.7
More than 2mm larger than last measurement	3	2.3
Total	129	100.0

When split further by ethnic group, this lack of fit was present in all ethnic groups but shown most strongly in Coloureds and Asians (100%), followed by White Africans (92%), and Black Africans (89.3%) as per Table 4.16.

Table 4.16: Heel to ball 1 frequency by CSID			
CSID		Frequency	Percent
ASI	More than 2mm smaller than last measurement	34	89.5
	Fits last measurement with 2mm margin either side	4	10.5
	Total	38	100.0
BAF	More than 2mm smaller than last measurement	23	82.1
	Fits last measurement with 2mm margin either side	5	17.9
	Total	28	100.0
COL	More than 2mm smaller than last measurement	23	60.5
	Fits last measurement with 2mm margin either side	13	34.2
	More than 2mm larger than last measurement	2	5.3
	Total	38	100.0
WAF	More than 2mm smaller than last measurement	18	72.0
	Fits last measurement with 2mm margin either side	6	24.0
	More than 2mm larger than last measurement	1	4.0
	Total	25	100.0

4.2.3.2.7 Heel to Ball 5

Comparison to this measurement indicated whether the fifth metatarsophalangeal joint would line up with the outer flex position of footwear formed on the “Ingrid” last. A tolerance of 2mm was allowed. The entire sample displayed a heel to ball 5 length that was more than 2mm shorter than the “Ingrid” last (Table 4.17)

Table 4.17: Heel to ball 5 frequency overall and by CSID			
CSID		Frequency	Percent
ASI	More than 2mm smaller than last measurement	38	100.0
BAF	More than 2mm smaller than last measurement	28	100.0
COL	More than 2mm smaller than last measurement	38	100.0
WAF	More than 2mm smaller than last measurement	25	100.0
Total	More than 2mm smaller than last measurement	129	100.0

4.2.3.2.8 Tape Forefoot Girth

Comparison to this measurement indicated whether the forefoot girth would fit within the forefoot girth provided by the last. More than three quarters of the group (85.3%) displayed a forefoot girth in excess of that of the last (Table 4.18).

Table 4.18: Tape forefoot girth frequency overall		
	Frequency	Percent
More than 2mm smaller than last measurement	11	8.5
Fits last measurement with 2mm margin either side	8	6.2
More than 2mm larger than last measurement	110	85.3
Total	129	100.0

When split further by ethnic group, this lack of fit was present in all ethnic groups but shown most strongly in Black Africans (89.3%), followed by Asians (86.8%), White Africans (84.0%) and Coloureds (81.6%) as per Table 4.19.

Table 4.19: Tape forefoot girth frequency by CSID			
CSID		Frequency	Percent
ASI	More than 2mm smaller than last measurement	1	2.6
	Fits last measurement with 2mm margin either side	4	10.5
	More than 2mm larger than last measurement	33	86.8
	Total	38	100.0
BAF	More than 2mm smaller than last measurement	3	10.7
	More than 2mm larger than last measurement	25	89.3
	Total	28	100.0
COL	More than 2mm smaller than last measurement	4	10.5
	Fits last measurement with 2mm margin either side	3	7.9
	More than 2mm larger than last measurement	31	81.6
	Total	38	100.0
WAF	More than 2mm smaller than last measurement	3	12.0
	Fits last measurement with 2mm margin either side	1	4.0
	More than 2mm larger than last measurement	21	84.0
	Total	25	100.0

4.2.3.3 Overall correlations for size 4 group

Pearson's correlation coefficient indicates a measure of association for two interval-ratio variables. In a similar way to ordinal measures of association, Pearson's "*r*" or correlation coefficient varies from 0 to +- 1, with 0 indicating no association and +1 and -1 indicating perfect positive and perfect negative relationships, respectively (Melville & Goddard, 1996:77).

If correlations are positive and *p*-values are above 0.5, then one can state that the linear relationship is fairly strong. This can be seen in Table 4.20 for the inter relationship between BMI and height and mass from which BMI is derived.

Table 4.20: Stature, mass and BMI correlations for actual size 4 group (N=129)					
** Pearson correlation is significant at the 0.01 level (2 tailed)					
* Pearson correlation is significant at the 0.05 level (2-tailed)					
	Overall	ASI	BAF	COL	WAF
Height to mass		-.422 **			
Height to BMI	-.441 **	-.645 **	-.417 *		
Height to major foot length				.364 *	
Height to Minor foot length	.300 **				.509 **
Height to Forefoot girth		-.362 *			
Mass to BMI	.929 **	.960 **	.944 **	.918 **	.931 **
Mass to toe height	.358 **	.418 **		.518 **	
Mass to tread width	.200 *	.458 **			
Mass to Heel seat width	.454 **	.625 **		.391 *	
Mass to Forefoot girth	.428 **	.531 **	.485 **	.350 *	
BMI to toe height	.371 **	.414 **		.476 **	
BMI to tread width	.226 *	.473 **			
BMI to heel width	.457 **	.549 **		.463 **	
BMI to forefoot girth	.418 **	.560 **	.475 *	.321 *	

Significant negative correlation ($p = -0.645$) exists at the 0.01 level (two-tailed) between height and BMI in the Asian/Indian group. In the Black African group, the negative correlation is significant ($p = -0.417$) at the 0.05 level (two-tailed) between height and BMI. A negative correlation is evidence of a general tendency that large values of X are associated with small values of Y and small values of X are associated with large values of Y. In both the Asian/Indian group as well as the Black African group, this means that there are large values of BMI associated with small values of height, and small values of BMI associated with large values of height. This result warrants investigation into obesity in these two groups.

A moderate negative correlation ($p = -0.362$) exists at the 0.05 level between height to forefoot girth only in Asian/Indian group, meaning that taller participants were associated with smaller forefoot girth and shorter participants were associated with larger forefoot girth in this group.

A positive correlation is evidence of a general tendency that large values of X are associated with large values of Y and small values of X are associated with small values of Y. Evidence of morphological changes to the foot associated with increased body mass are seen most in the Asian/Indian group, followed by the Coloured group and to a lesser extent in the Black African group.

Specifically, four foot variables show positive correlations at the 0.01 level (two-tailed) to body mass in the Asian/Indian group ($p = 0.625$ mass to heel seat width, $p = 0.531$ mass to forefoot girth, $p = 0.458$ mass to tread width and $p = 0.418$ mass to toe height). In the Coloured group, one foot variable shows positive correlations at the 0.01 level (two-tailed) to body mass ($p = 0.518$ mass to toe height, while two foot variables show positive correlations at the 0.05 level (two-tailed) to body mass ($p = 0.391$ mass to heel seat width and $p = 0.350$ mass to forefoot girth). In the Black African group, only one foot variable shows positive correlation at the 0.01 level (two-tailed) to body mass ($p = 0.485$ mass to forefoot girth). None of the foot variables showed correlation to body mass in the White African group.

4.2.3.3.1 Summary of comparisons to the last

The listing in Table 4.21 summarises minimum, maximum and average values for foot measurement variables and identifies those average foot measurements (marked *) that are disparate with the measurement taken from the last.

Description	Analysis size 4 only (228mm to 237mm foot length)	Comparable Measurements “Ingrid” Last UK Size 4
N	129	1
Overall foot length min length max length	234 mm average 228mm 237mm	243mm
Length to tip of 5 th toe min length max length	195.74 mm average 182mm 206mm	193mm *
Big toe height min height max height	22.68 mm average 17mm 32mm	22mm
Tread width min width max width	91.05mm average 78mm 103mm	83mm *
Heel seat width min width max width	62.97 mm average 47mm 73mm	52mm *
Heel to Ball 1 min position max position	174.22 mm average 163mm 183mm	179mm
Heel to Ball 5 min length max length	157.28 mm average 144mm 168mm	173mm
Joint girth min girth max girth	228.25 mm average 180mm 275mm	214mm *

Asterisks (*) denote inadequate last measurement to suit average feet in the sampled group. The relevance of the shortcomings of a last with regard to heel seat width, forefoot or tread width, forefoot or joint girth and minor foot length will be discussed in 5.3.

4.3 Part three: Scaleable measurement comparison

The second group of data was formed by scaling of all scanned feet, other than those considered to be a “natural” size 4, to a foot length of 234mm. By so doing, all other dimensions of the foot were scaled to the same proportion as the one used to bring the foot length to 234mm. This second group consisted of 324 data records.

This enabled a comparison of means of both the data sets; one that corresponds to an actual “naturally” size 4 foot ($N = 129$), and the other to the new re-scaled size 4 data ($N = 324$) by means of a t -test for two independent sample means, to establish whether there is any significant ($p < 0.05$) difference between the means.

4.3.1 Descriptives and t -test results

In Table 4.22 measures of central tendency (mean and standard deviation) for the scaled size 4 group ($N = 324$) are summarized.

Table 4.22: Statistics for scaleable comparison groups				
	Group	N	Mean	Std. Deviation
A: Major foot length	Natural 4	129	234.0000	.00000(a)
	Re-Scaled 4	324	234.0000	.00000(a)
B: Minor foot length	Natural 4	129	195.7442	4.37550
	Re-Scaled 4	324	195.7994	4.59302
C: Toe height	Natural 4	129	22.6822	2.44305
	Re-Scaled 4	324	22.1728	2.31720
D: Tread width	Natural 4	129	91.0465	4.56526
	Re-Scaled 4	324	90.5093	4.78419
H: Heel seat width	Natural 4	129	62.9690	4.32821
	Re-Scaled 4	324	62.6852	4.97482
J: Heel ball 1	Natural 4	129	174.2248	4.01022
	Re-Scaled 4	324	173.6790	3.65993
K: Heel ball 5	Natural 4	129	157.2868	4.61179
	Re-Scaled 4	324	156.9012	4.97574
L: Tape forefoot girth	Natural 4	129	228.2558	12.29410
	Re-Scaled 4	324	227.3272	13.15934

A= t cannot be computed because the standard deviations of both groups are 0.

Results of the *t*-test are summarized in Table 4.23. The *t*-test results show that only the mean toe height measurement is significantly different [$p = 0.038$, $t(451) = 2.079$] between the two groups.

This suggests, firstly, that only the dimension of toe height should be scaled differently to the scaling proportion applied to foot length increments by size.

Secondly, because the *t*-test does not show significant difference between the means of the two groups in any other of the measured dimensions, this means that proportions for any dimension in reality are the same as that applied to length as the foot increases in size. This is in conflict with current industry practice as detailed in 3.4.

Table 4.23: Independent Samples Test								
Equal variances assumed								
	Levene's Test for Equality of Variances		t-test for Equality of Means					
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
							Lower	Upper
B: Minor foot length	.084	.772	-.117	451	.907	-.05520	-.98250	.87210
C: Toe height	1.044	.307	2.079	451	.038	.50933	.02779	.99087
D: Tread width	.401	.527	1.093	451	.275	.53725	-.42907	1.50358
H: Heel seat width	2.771	.097	.568	451	.570	.28381	-.69829	1.26590
J: Heel ball 1	2.049	.153	1.393	451	.164	.54579	-.22403	1.31562
K: Heel ball 5	.031	.860	.760	451	.448	.38559	-.61186	1.38304
L: Tape forefoot girth	1.118	.291	.690	451	.490	.92865	-1.71466	3.57196

4.3.2 Comparison summary

In a similar way to the layout of Table 4.21, Table 4.24 shows the minimum, maximum and average values for foot measurement variables for both the “natural size 4 group and the “re-scaled” size 4 group and identifies those average foot measurements (marked *) that are disparate with the measurement taken from the last.

Table 4.24: Comparison of mean measurements between both groups and the last.			
	Analysis size 4 only (228mm to 237mm foot length)	Analysis all feet rescaled to 234mm foot length	Comparable Measurements “Ingrid” Last UK Size 4
<i>N</i>	129	324	
Overall foot length min length max length	234 mm average 228mm 237mm	234mm average	243mm
Length to tip of 5 th toe min length max length	195.74 mm average 182mm 206mm	195.79 mm average 182mm 208mm	193mm *
Big toe height min height max height	22.68 mm average 17mm 32mm	22.17 mm average 17mm 32mm	22mm
Tread width min width max width	91.05mm average 78mm 103mm	90.51 mm average 77mm 106mm	83mm *
Heel seat width min width max width	62.97 mm average 47mm 73mm	62.68 mm average 38mm 78mm	52mm *
Heel to Ball 1 min position max position	174.22 mm average 163mm 183mm	173.68 mm average 164mm 186mm	179mm
Heel to Ball 5 min length max length	157.28 mm average 144mm 168mm	156.90 mm average 139mm 170mm	173mm
Joint girth min girth max girth	228.25 mm average 180mm 275mm	227.33 mm average 182mm 275mm	214mm *

Asterisks (*) denote inadequate last measurement to suit average feet in both groups.

The relevance of the shortcomings of a last with regard to heel seat width, forefoot or tread width, forefoot or joint girth and minor foot length will be discussed in 5.3.