DEVELOPING SIZE CHARTS FOR PETITE SOUTH AFRICAN WOMEN FROM 3D BODY SCANNED E-TAPE MEASUREMENTS

Masejeng M Phasha*, Simon Harlock & Reena Pandarum

ABSTRACT

The purpose of this study was to develop upper and lower body dimensions' size charts for a sample of 200 petite South African women aged 20-54 years residing in Gauteng and with a height of 163 cm or below as determined from their e-tape anthropometric measurements obtained using a 3D full body scanner. The most prevalent body shape was found to be pear shaped (n=180). The size charts were evaluated by comparing the body measurements for a size 10/34 with a correspondingly sized commercial petite mannequin and the respective fit of shirt and trouser garments manufactured to fit a sample of nine size 10/34 women.

The findings show that the 3D e-tape generated measurements from the size charts for the size 10/34 petite women produced an overall better quality of fit than the garments made using the e -tape measurements of the size 10/34 petite tailoring mannequin. The study highlights the current limitations of the petite women sizing charts in use in the South African apparel industry.

— Ms MM Phasha*
Department of Life and Consumer Science
College of Agriculture and Environmental Sciences
University of South Africa
South Africa
Tel: +27 (0) 78 2177 689
E-mail: phashamarion@gmail.com
*Corresponding Author

— Mr S Harlock
Department of Life and Consumer Science
College of Agriculture and Environmental Sciences
University of South Africa
South Africa
Tel: +27 (0) 11 471 2550
Email: simonharlock@hotmail.com

— Ms R Pandarum
Department of Life and Consumer Science
College of Agriculture and Environmental Sciences
University of South Africa
South Africa
Tel: +27 (0) 11 471 2550
Email: pandak@unisa.ac.za

ARTICLE INFO

Submitted January 2020
Revision July 2020
Accepted December 2020

KEYWORDS

South African petite women, 3D body scanner, body shapes, garment sizing and fit, size charts

INTRODUCTION

Petite women are defined differently by various authors and researchers both nationally and internationally. Defty (1988), Winks (1990), Barona-McRoberts (2005) Bailey (2010) and Kim *et al.* (2016) define a petite woman as being short in body stature. However, Bailey (2010) suggests that petite women's garments are manufactured principally with an emphasis on body height, which is 5'4" (163 cm) and below. Kim's (1993), study argues that petite women require their own sizing categories for ready-to-wear garments, as petite women's body proportions are different when compared to those of the “average” woman. Therefore, female consumers, particularly petite consumers, who have a body shape that does not conform to that of an apparel retailer’s target market might experience problems with the fit of garments sold in retail stores (Park *et al.,*2009) because manufacturers use standard-sized body measurements and common garment size categories for the average women consumer (Bye *et al.,* 2006).

Since the 1980s, 3D body scanners have steadily replaced traditional anthropometry for generating shape and sizing data (Apeagyei, 2010) by providing a means for capturing and analysing data and, thereby, a direct link between the recorded data, pattern design and garment construction (Petrova & Ashdown, 2008).

Therefore, the aim of this study was to develop size charts from 3D anthropometric e-tape measurements for petite women and, thereafter, evaluate the accuracy of fit of the garments produced using the size charts with those produced using a petite tailoring mannequin, currently used commercially to manufacture garments for petite South African women. The objective of the study was to answer the following research questions:

1. What are the upper and lower body size charts measurements derived from 3D body scanned petite subjects’ e-tape data for the most prevalent body shape arising in this study?

2. How do the e-tape measurements developed for the upper and lower body size charts in this study compare with the commercially used petite tailoring mannequin’s e-tape measurements?

An overview of reported sizing and fit studies conducted for petite women in South Africa

The only known South African studies conducted for petite women are those of Defty (1988), Winks (1990), and Bailey (2010), all of which used traditional, dress-makers tape measurements. Defty’s (1988) study used the measurements of women without shoes, based on their width and the body height measurement of 153 cm to develop a size chart for “short”/ petite women. The size chart developed from the study was classified as generic data according to the subject’s body type. Winks’ (1990) study identified body size distribution measurements of three female ethnic groups, whites, blacks and coloureds and defined a mean body height measurement of 160 cm for petite women. Bailey (2010:23) is the only reported study that established a size chart for petite women between the ages of 18-30 with the height of 160cm and below. However, the measurements were derived by grouping the data into three petite garment size ranges of 2, 4, and 6 limited to three body landmarks; viz. the bust, waist and hip girths.

Garment sizing and fit reported for South African women

Muthambi (2012:62) proposed an experimental size chart (from size 4/30 - 14/38) for 60 young women of African descent triangular body shapes, aged 18-25 years. The findings from the study, revealed that triangular shaped South African women generally have slightly shorter vertical measurements. Ola-Afolayan’s and Mastamet-Mason’s (2013:206), tape measured study reported a customised size chart (from size 16-24) for 50 South African pear-shaped plus-sized women of African origin, aged 25-55 years. The findings indicated that the current body measurements presented in size charts used for manufacturing garments for South African women differ significantly from their customised size measurements, suggesting the need to develop a size chart that cater for the pear shape profile.

Bailey’s (2010) petite study also evaluated clothing perceptions and confidence in women’s clothing. The findings from Bailey’s (2010:22) are that subjects were at some point unhappy with the ready-to-wear petite women’s garments sold in retail stores and were not adequately accommodated in terms of well-fitting garments.

According to Kahn (2008), the majority of garment manufacturers and retailers in South Africa are not conscious of the changing body shapes and sizes of the South African women. Researchers (Mbandazayo *et al.,* 2014; Muthambi, 2012; Ola-Afolayan and Mastamet-Mason, 2013; Pandarum & Yu, 2015; Sokhetye, 2016; Strydom, 2006) suggest that garments manufactured for South African women were adapted from British, mainland European and American sizing systems. The garments might not offer a satisfactory fit to the South African female consumers since the data was not developed specifically for the South African women's clothing market.

Furthermore, a South African mannequin manufacturer, Figure Forms, claims that a measurement specification sheet for petite women, developed in 2003, was based on a total body height measurement of 160 cm. To date, this is the only known petite mannequin developed for petite women in the country (Milliam, 2017). Hence, the lack of information on petite South Africa's woman's anthropometric data is acknowledged, and the relationship between the South African petite women's body dimensions and apparel fit is largely unknown.

METHODOLOGY

Research design

This study applied a quantitative approach, using purposive and convenience sampling methods to recruit and collect data from a sample of 200 petite women, based on a height range of 5' 4" (163 cm) and below, aged 20 to 54 years, residing in Gauteng, South Africa. The sample size was initially based on The Statistics SA (2014) report of women population residing in Gauteng. Participation was voluntary, and each subject signed a consent form guided by the Ethical Clearance Number 2015/CAES/116. A (TC)² NX16 3D full body scanner was used to collect and identify the subjects' body shapes using a customised shape identification programme in the scanner interface. Body weight and height measurements were collected using an Adam's® medical scale as the scanner does not automatically take these measurements.

During the scan generation process, the scanner automatically generated the XYZ coordinates of each point in the point cloud of each scanned image. The measurements of the body landmarks required for constructing a basic shirt and trouser garments were extracted using a researcher input measurement extraction programme (mep), selected from a list of body landmarks available on the (TC)² NX16 3D full body scanner measurement system. The mep was set to extract data according to the SANS 8559-1 (2019) standard protocols for reproducibility. The resulting anthropometric e-tape data extracted by the scanner used the petite subject's bust, upper waist, and hip girth body point of measures to classify the body shape. Thereafter, the women were sorted and classified into body shapes using the body shape software in the scanner interface. This resulted in a final sample size of 180 pear shaped women, which was the most prevalent body shape within the original sample of 200 women.

Size chart development for the upper and lower body dimensions

Multivariate data analysis based on Principal component analysis (PCA) was used to analyse the 3D body scanned e-tape data to gain an in depth understanding into the characteristics of the petite women dataset. Body dimensions that correlated to one another were then clustered into factor loadings to define the primary body dimensions for developing the size charts and thereafter, to identify the relationship between the primary and secondary body dimensions. According to Zakaria (2014:96), the primary body dimensions define an individual's body size and is used as control dimensions to develop a sizing system to assign garment size ranges. The secondary dimensions are often used together with the primary body dimensions to define the full body size of a person.

The PCA selected 14 upper body dimensions (namely; the neck full, shoulder, armscye, bicep, elbow, wrist, chest, bust, underbust, upper waist, lower waist, neck to upper waist (back), neck to upper waist (front) and the sleeve length) required for creating garments such as shirts and 13 lower body dimensions (namely; upper waist, lower waist, high hip, hip, top thigh, mid-thigh, knee, calf, ankle, outseam, inseam, crotch length front, crotch length back) for creating garments such as trousers. The upper waist and lower waist measurements were represented in both the upper and lower body dimensions.

A significance level of 0.05 was used for testing the correlations of the body dimensions in this study based on a two-tail significance test. The p -values observed in the analysed data showed a significant relationship between the analysed body dimensions.

Regression analysis was used to predict the value of the secondary body dimensions (dependent variable) using the primary body dimensions as the independent variable. In some instances, multiple regression was applied since there were two identified primary body dimensions, rather than one. Examples using the waist and bust as primary body dimensions for the upper girth measurements and underbust girth as the secondary measurements are presented in Steps 1 to 5 below.

Step 1: The Descriptive Statistics in the regression model were analysed to provide the mean and standard deviation for both the explanatory and outcome variables (see table 1).

The mean values of the primary body dimensions were used in the regression calculation to predict the measurement values of the secondary body dimensions.

Step 2: Correlations among the variables were analysed to predict those secondary variables that were strongly associated with the primary body dimension. The number of cases used for each correlation was determined on a "pairwise" basis, for example there were 180 valid pairs of data meaning that the entire pear shape sample size was covered in the regression analysis. Step 3: The Model Summary was analysed to provide the correlation coefficient and coefficient (R squared) for the regression model (refer to table 2).

The "R Squared" coefficient indicates the total variation in the underbust girths and can be explained by the waist and bust girth variables. In this case, the coefficient of 0.923 suggests there is a strong positive relationship between the analysed body dimensions which proves that the regression analysis is good for predicting the secondary underbust body dimension.

Step 4: The ANOVA table 3 was used to report the extent to which the regression model explained a statistically significant proportion of the variance.

Ratios were used to compare how well the regression model predicted the mean measurement values of the primary dimension

TABLE 1: DESCRIPTIVE STATISTICS FOR THE UPPER BODY DIMENSIONS FOR THE SHIRT GIRTH MEASUREMENTS)

Descriptive Statistics			
	Mean	Std. Deviation	N
UNDERBUST	87.36	14.894	180
WAIST	82.45	14.588	180
BUST	100.19	14.326	180

TABLE 2: THE MODEL SUMMARY FOR DETERMINING THE R-SQUARE

Model Summary[b]				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.961[a]	.923	.922	4.148

*a. Predictors: (Constant), BUST, WAIST
*b. Dependent Variable: UNDERBUST

TABLE 3: THE ANOVA TABLE USED TO REPORT HOW WELL THE REGRESSION EQUATION PREDICTS THE UNDERBUST SECONDARY BODY DIMENSION AND HOW SIGNIFICANT THE PREDICTIONS WERE

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	36665.207	2	18332.604	1065.560	.000[b]
	Residual	3045.226	177	17.205		
	Total	39710.433	179			

*a. Dependent Variable: UNDERBUST
*b. Predictors: (Constant), BUST, WAIST

TABLE 4: THE REGRESSION COEFFICIENTS FOR PREDICTING THE UNDERBUST ESTIMATES EQUATION

Coefficients[a]						
		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	-6.709	2.279		-2.944	.004
	WAIST	.408	.055	.400	7.470	.000
	BUST	.603	.056	.580	10.848	.000

*a. Dependent Variable: UNDERBUST

as an estimate for the secondary body dimension. Values less than 0.05 were considered significant (Zakaria, 2014). Given the strength of the correlations in step 2 there was a positive relationship between both the waist and bust primary body dimensions with the underbust body dimensions.

Step 5: The regression coefficients presented in table 4 for predicting the underbust estimates equation were established using "unstandardized" coefficients.

The beta coefficients were used to compare the relative strength of the various predictors within the model such as the waist and bust. The coefficients for both the waist and bust were observed as positive, indicating that, as the waist and bust measurements increased, the underbust measurements also increased. The resulting regression equation for predicting the underbust was y = -6.709 + (0.408*waist mean measurement) + (0.603* bust mean measurement). To determine the size interval, the primary body dimension's minimum measurement value was subtracted from the maximum measurement value of that specific primary body dimension, thereafter, dividing the difference by the number of size ranges to be allocated in the size charts (see figure 1 for the underbust calculations).

These results suggested that the overall regression analysis provided a good method of predicting the underbust and other measurements for the size charts.

Size chart evaluation

In order to evaluate the relevance of the size charts, shirt and trouser pattern pieces were drafted using the size 10/34 measurements developed from the upper and lower body size charts and the size 10/34 petite tailoring mannequin's measurements which were subsequently used to produce garments from a calico cotton fabric, as recommended by (Redmore, 2012:10; Trish Newbery Design, 2014).

The procedures for drafting the pattern blocks were adapted from Defty's (1988:22-30) pattern making book with modifications to accommodate the body measurements arising in this study supplemented by the researcher's pattern making experience, with two academic experts who had approximately 6 and 15 years respectively of experience in the clothing field.
The justification for using Defty's pattern drafting method, in this study, was that Defty (1988:17-18) is the only South African author who published upper and lower body size charts for petite "short" women and additionally provided

B	C	D	E	F	G	H
		Constant	Waist	Bust		
	underbust	-6,709	0,408	0,603		
		To determine the size interval				
		waist	131-60= 71/11 = 6.4 rounded up to 6			
		bust	140-74 =66/11= 6			
			Mean			
		waist	82	6		
		bust	100			
underbust	87		2	4		6

FIGURE 1: CALCULATIONS FOR ALLOCATING THE AVERAGE UNDERBUST GIRTH MEASUREMENT FOR THE UPPER BODY SIZE CHART

pattern making instructions for drafting the bodice, sleeve for the shirt garments and the "slacks" for the trouser garments.

Wearer fit tests conducted using the prototype garment

The apparel industry uses fit models or tailoring mannequins to establish the fit and drape of a given garment style on the body based on an industry established base-size as determined by their target markets. Fit models may differ in measurements and proportions, according to the retailer or manufacturer's target market (Alexander *et al.,* 2005).

This petite women study used live human fit models and the industry standard petite tailoring mannequin to test the quality of fit of the prototype garments manufactured in the study. The subjects were chosen from those that were 3D scanned and stated that they purchase ready to wear garments in a size 10/34.

Nine subjects with pear body shape profiles who were available and whose measurements, as extracted by the 3D body scanner, corresponded to the size 10/34 measurements in the upper and lower body dimensions' size charts were evaluated for the garment fit test trials. The study tested garment fit on the subjects who represented the size variability within the lower-end to the higher-end of the established size 10/34 size range measurements. A panel of two expert lecturers in the clothing department at UNISA evaluated the fit qualities of the prototype shirt and trouser garments developed in the study. The evaluators were provided with rating scales and written standards consisting of descriptions of the criteria to evaluate the quality of fit of the prototype garments.

The standards for evaluating the fit of the test garments were structured around five principle components of garment fit i.e. ease, line, grain, balance and set. adapted from Stamper *et al.* (2005), Liechty *et al*. (2010:54) and Marshall *et al*. (2012).

RESULTS AND DISCUSSIONS

The developed experimental upper and lower body dimensions' size charts from the 3D body scanned petite subject's measurements

The findings from the PCA and regression analysis as shown in the highlighted body dimensions (see table 5, for the upper body dimensions, and table 6, for the lower body

TABLE 5: A ROTATED COMPONENT MATRIX SHOWING FACTOR LOADINGS FOR THE UPPER BODY DIMENSIONS REQUIRED FOR DEVELOPING THE PROTOTYPE SHIRT PATTERN BLOCK

Rotated Component Matrix for the upper body dimensions				
BODY DIMENSIONS		Component		
		1	2	3
GIRTHS	BUST	.928		
	UPPER WAIST	.920		
	UNDERBUST	.904		
	LOWER WAIST	.903		
	CHEST	.883		
	BICEP	.879		
	ELBOW	.788		.370
	NECK FULL	.742		
	ARMSCYE	.728		
LENGTHS	NECK TO UPPER WAIST (Back)		.950	
	NECK TO UPPER WAIST (Front)		.946	
	SHOULDER			
	SLEEVE			-.837
GIRTH	WRIST	.415		.604

TABLE 6: A ROTATED COMPONENT MATRIX SHOWING FACTOR LOADINGS FOR THE LOWER BODY DIMENSIONS REQUIRED FOR DEVELOPING THE PROTOTYPE TROUSER PATTERN BLOCK

Rotated Component Matrix for the lower body dimensions				
BODY DIMENSIONS		Component		
		1	2	3
GIRTHS	TOP THIGH	.888		
	CALF	.872		
	UPPER WAIST	.868		
	LOWER WAIST	.860		
	HIP	.848	.390	
	MID-THIGH	.847		.365
	HIGH HIP	.748	.473	-.357
	ANKLE	.301		
	KNEE			
LENGTHS	CROTCH LENGTH BACK		.929	
	CROTCH LENGTH FRONT		.925	
	INSEAM		-.435	.842
	OUTSEAM		.543	.804

dimensions) show the critical body length and girth measurements required when manufacturing shirt and trouser garments (Gupta & Gangadhar, 2004:465; Petrova, 2007:64,70; Zakaria, 2014:113). The PCA also indicated the primary body landmarks to use in the classification of the upper and lower body size charts. Four primary body dimensions (namely, the bust, upper waist, neck to upper waist back and sleeve length) were identified from the upper body dimensions and five primary body dimensions (upper waist, lower waist, hip, crotch length back and inseam) for the lower body.

According to Milliam (2017) sizing in the apparel industry is based on a standard sample size of 10/34. In the absence of a representative anthropometric dataset of South African petite women, the primary measurements derived from the subjects' 3D body scanned e-tape data that were observed to be closest to those of the size

10/34 petite e-tape tailoring mannequin measurements were used to define the base size 10/34 for the developed size charts. A total of 11 size ranges from a size 6/30 to 26/50 were established from the 3D body scanned petite subjects' measurements covering 98% (n=177) for the upper body and 97% (n=175) respectively for the lower body of the 180, 3D body scanned petite pear shaped women (see table 7 and table 8).

The measurement comparisons between the developed size 10/34 size chart measurements, the 3D body scanned petite mannequin, Defty's (1988:17-18) and Winks (1990:74-76) are presented in table 9 for the upper body measurements and table 10 for the lower body measurements.

The petite subjects' average height defined in this study was 157 cm. The average height range from both the 3D body scanned petite mannequin and Winks' (1990:74-76) was 160 cm, whilst Defty's (1988:17-18) average height was 153 cm. The comparison between the size 10/34 size chart measurements derived in this study and that of Defty's (1988:17-18) and Winks' (1990:74-76) size charts was limited since the researchers only listed a few measurements in their size charts that corresponded with the measurement specifications derived for the upper and lower body dimensions' size charts in this study. Four body measurements; namely: the height, bust, waist and hip from Defty's (1988:17-18) and only three body measurements; namely: the height, bust and hip from Winks' (1990:74-76) studies were applicable for comparison with body measurements derived for this study.

For the bust and hip measurements, the subjects' size 10/34 bust measurements were the same as Defty's and Winks' bust measurements. Therefore, it may be inferred that the bust fit would be similar for the shirt garments. Manufacturing the trouser garment using Defty's hip measurement may affect the fit of the garment on the subjects' body, resulting in a slightly tight fit in the hip. Defty's hip measurement was 3 cm smaller than the subjects' size 10/34 hip measurement. The fit of the trouser garments at the hip would be similar if Winks' data was used to make the trouser garment because Winks' hip measurement was only 1 cm smaller than the subjects' size 10/34 hip measurement.

Results from the wearer fit test trials of the prototype shirt and trouser garments

The prototype shirt and trouser garments were evaluated by experienced clothing lecturers to assess the quality of fit of the shirt and trouser garments using three rating scale categories. A good fit rating scale (3) indicated that the garment fitted well, a moderate fit rating scale (2) indicated that the fit of the garment was acceptable and a poor fit rating scale (1) indicated that the garment did not fit well on the wearer's body.

Each evaluator's fit rating values were added together to establish the overall mean scores for the fit of the garments, for each of the nine subjects, manufactured using both the 3D body scanned e-tape size chart measurements and the scanned e-tape petite mannequin's measurements. Thereafter, the overall mean rating values established for each of the assessed garment per subject was compared together to determine the extent to which of the created garments offered an overall good quality of fit (refer to table 11 for the overall shirt mean value rating scales and table 12 for the overall trouser mean value rating scales).

The accuracy of the e-tape developed size charts compared to the petite tailoring mannequin's e-tape measurements

The results from the overall quality of fit attained from the fit rating scales showed that the garments manufactured from the petite subjects' size 10/34 size range measurements produced an overall better quality of fit than the garments made to fit the currently commercially available size 10/34 petite mannequin. Additionally, both the shirt and trouser garments produced using the petite mannequin's measurements were longer in garment length than those produced from the size chats measurements. To

TABLE 7: THE EXPERIMENTAL UPPER BODY SIZE CHART (WITH SIZE INTERVALS) FOR SOUTH AFRICAN PETITE WOMEN

PETITE WOMEN'S SIZE CHART FOR THE UPPER BODY DIMENSIONS (cm)																						
	SIZE RANGES	**6/30**		**8/32**		**10/34**		**12/36**		**14/38**		**16/40**		**18/42**		**20/44**		**22/46**		**24/48**		**26/50**
	Bust	76	6	82	6	88	6	94	6	100	6	106	6	112	6	118	6	124	6	130	6	136
GIRTHS	**Upper waist** (at navel, midriff area)	58	6	64	6	70	6	76	6	82	6	88	6	94	6	100	6	106	6	112	6	118
	Chest	78	5	83	5	88	5	93	5	98	5	103	4	107	5	112	5	117	5	122	5	127
	Underbust	63	6	69	6	75	6	81	6	87	6	93	6	99	6	105	6	111	6	117	6	123
	Lower waist (15cm below the upper waist)	68	7	75	6	81	7	88	6	94	7	101	6	107	7	114	7	121	6	127	7	134
	Bicep	24	2	26	2	28	2	30	1	31	2	33	2	35	2	37	2	39	2	41	2	43
	Elbow	20	1	21	2	23	1	24	2	26	1	27	2	29	1	30	2	32	1	33	2	35
	Neck full	32	1	33	2	35	1	36	1	37	1	38	1	39	1	40	1	41	1	42	2	44
	Armscye	33	1	34	2	36	2	38	1	39	2	41	1	42	2	44	2	46	1	47	2	49
LENGTHS	**Neck to upper waist back**	29	2	31	2	33	2	35	2	37	2	39	2	41	2	43	2	45	2	47	2	49
	Neck to upper waist front	27	1	28	2	30	1	31	1	32	2	34	1	35	2	37	1	38	2	40	1	41
SLEEVE AREA	**Sleeve length** (shoulder-wrist)	46	1	47	1	48	1	49	1	50	1	51	1	52	1	53	1	54	1	55	1	56
	Shoulder length	12	0	12	0	12	0	12	0	12	0	12	0	12	0	12	0	12	0	12	0	12
	Wrist	16	0	16	0	16	0	16	0	16	0	16	0	16	0	16	0	16	0	16	0	16

*The highlighted size 14/38 represent the average measurements established from the subjects' scanned data

TABLE 8: THE EXPERIMENTAL LOWER BODY SIZE CHART (WITH SIZE INTERVALS) FOR SOUTH AFRICAN PETITE WOMEN

PETITE WOMEN'S SIZE CHART FOR THE LOWER BODY DIMENSIONS cm)																						
	SIZE RANGES	**6/30**		**8/32**		**10/34**		**12/36**		**14/38**		**16/40**		**18/42**		**20/44**		**22/46**		**24/48**		**26/50**
GIRTHS	**Upper waist**	58	6	64	6	70	6	76	6	82	6	88	6	94	6	100	6	106	6	112	6	118
	Lower waist (15cm below the upper waist)	67	7	74	7	81	7	88	7	95	7	102	7	109	7	116	7	123	7	130	7	137
	Hip (20cm below lower waist)	84	6	90	6	96	6	102	6	108	6	114	6	120	6	126	6	132	6	138	6	144
	Top thigh	50	3	53	2	55	2	57	3	60	2	62	2	64	3	67	2	69	2	71	3	74
	Mid-thigh	41	2	43	2	45	2	47	2	49	2	51	2	53	2	55	2	57	2	59	2	61
	Calf	31	2	33	2	35	1	36	2	38	2	40	2	42	1	43	2	45	2	47	2	49
	high hip (10cm below lower waist)	78	6	84	6	90	6	96	7	103	6	109	6	115	6	121	6	127	6	133	7	140
	Ankle (under the feet-over side ankle bones)	25	1	26	0	26	1	27	0	27	1	28	1	29	0	29	1	30	0	30	1	31
	Knee	40	0	40	1	41	0	41	0	41	0	41	1	42	0	42	0	42	0	42	1	43
CROTCH AREA	**Crotch length back**	29	3	32	3	35	3	38	3	41	3	44	3	47	3	50	3	53	3	56	3	59
	Crotch length front	29	2	32	2	34	3	37	3	40	2	42	3	45	2	47	3	50	2	52	3	55
LENGTHS	**Inseam** (inside leg length)	60	3	63	3	66	3	69	3	72	3	75	3	78	3	81	3	84	3	87	3	90
	Outseam (outside leg length)	98	1	99	1	100	2	102	1	103	1	104	1	105	2	107	1	108	1	109	1	110

*The highlighted size 14/38 represent the average measurements established from the subjects' scanned data

substantiate these findings, an example of the fit test trials is presented in figure 2.

However, discrepancies were observed in some body dimensions for the fitted size 10/34 petite subject measurements when compared to the size 10/34 experimental size chart measurements. The sleeve circumference dimensions such as the bicep, elbow and some wrist areas were tight for both of the assessed shirt garments, indicating that more ease allowances should be added. This could also indicate a shortcoming in the correlation between bust girth measurements with the sleeve arm girth measurements.

Discrepancies were also observed between the trouser garment girth measurements such as the thigh, knee and ankle with the trouser garment length (inseam and outseam) measurements, where the girth areas exhibited wrinkles indicating that the pattern should be manipulated to adjust the problems. The wrinkles observed along the crotch area, show that adjustments should be made in the crotch area. The crotch curve should be raised in and slightly shortened to remove excess fabric from the front area to create a flattering fit. The back crotch should be slightly extended at the back point, particularly for the petite tailoring mannequin's pattern to reduce the tight fit and drag lines from forming from the hip to the ankle area. Another option is to adjust the inseam and outseam slightly inwards on the pattern to reduce the access

TABLE 9: COMPARISON BETWEEN THE SIZE 10/34 PETITE SIZE UPPER BODY MEASUREMENTS

		3D body scanned data of petite subjects (Size 10/34)	Differences between the 3D body scanned petite subjects and the petite mannequin's measurements	3D body scanned petite mannequin	Differences between the 3D body scanned petite subjects and Defty's measurements	Defty (1988:17-18)	Differences between the 3D body scanned petite subjects and Winks' measurements	Winks (1990:74-76)Based on the M body type
	HEIGHT (mean/average)	157cm	+3	160cm	-4	153cm	+3	160cm
GIRTHS	BUST	88	-2	86	0	88	0	88
	UPPER WAIST (at navel, midriff area)	70	-1	69	-4	66	-	-
	NECK FULL	35	-1	34	-	-	-	-
	ARMSCYE	36	-3	33	-	-	-	-
	BICEP	28	-1	27	-	-	-	-
	ELBOW	23	-3	20	-	-	-	-
	CHEST	88	-1	87				
	UNDERBUST	75	-2	73	-		-	-
	LOWER WAIST (15cm below the upper waist)	81	+4	85	-	-	-	-
LENGTHS	NECK TO UPPER WAIST (front)	30	+5	35	+3	33	-	-
	NECK TO UPPER WAIST (back)	33	+6	39	-	-	-	-
SLEEVE AREA	SLEEVE LENGTH (shoulder-wrist)	48	+3	51	-	-	-	-
	SHOULDER	12	0	12	-	-	-	-
	WRIST	16	-1	15	-	-	-	-

TABLE 10: COMPARISON BETWEEN THE SIZE 10/34 PETITE SIZE LOWER BODY MEASUREMENTS

		3D body scanned data of petite subjects (Size 10/34)	Differences between the 3D body scanned petite subjects and the petite mannequin's measurements	3D body scanned petite mannequin	Differences between the 3D body scanned petite subjects and Defty's measurements	Defty (1988:17-18)	Differences between the 3D body scanned petite subjects and Winks' measurements	Winks (1990:74-76) Based on the M body type
	HEIGHT (mean/average)	157cm	+3	160cm	-4	153cm	+3	160cm
GIRTHS	WAIST (at navel, midriff area)	70	-1	69	-4	66	-	-
	LOWER WAIST (15cm below the upper waist)	81	+4	85	-	-	-	-
	HIP (20cm below lower waist)	96	-1	95	-3	93	-1	95
	HIGH HIP (10cm below lower waist)	90	+2	92	-	-	-	-
	TOP THIGH	55	-1	54	-	-	-	-
	MID THIGH	45	-4	41	-	-	-	-
	CALF	35	-1	34	-	-	-	-
	ANKLE (under the feet-over side ankle bones)	26	-1	25	-	-	-	-
	KNEE	41	-2	39	-	-	-	-
CROTCH AREA	CROTCH LENGTH FRONT	34	+2	36	-	-	-	-
	CROTCH LENGTH BACK	35	+1	36		-	-	-
LENGTHS	INSEAM (inside leg length)	66	+7	73	+5	71	-	-
	OUTSEAM (outside leg length)	100	+2	102	-4	96	-	-

width measurements along the thigh, knee and ankle areas, this applies more to the trouser garment created using the size chart measurements. Although, minor wrinkles were observed in some of the subjects' upper trouser, the waist to hip girth measurement correlations of the size 10/34 size chart measurements seemed to produce a better fit. Furthermore, some of the subject's girth and length measurements when compared with the size 10/34 size chart size range measurements shifted to another size range.

CONCLUSIONS

This is the first study to specifically 3D body scan petite South African women, develop and evaluate a set of size charts based on their 3D anthropometric e-tape measures. Therefore, it represents a significant contribution towards gaining a greater insight into garment fit issues of petite South African women consumers.

The findings of the study suggest that the collection of realistic and up-to-date anthropometric body measurements using 3D body scanners has the potential for contributing to better fitting garments. The wearer trials indicated that the size chart shirt and trouser garment lengths were shorter than the length of the shirt and trouser garments created using the petite mannequin. The petite subjects' body height and length proportion ratios were shorter than those of the petite mannequin. The shirt sleeve girth area was found to be tight fitting for both of the assessed garments. From the results, it is evident that the fit of the shirt and trouser garments was affected by the height and body dimensions of the subjects.

The methodology used in this study has shown that size charts created from body scanned data resulted in an improved fit for both the shirt and trouser garments; giving an avantage over those produced using a commercial mannequin for South African petite women. On the evidence of

TABLE 11: COMPARATIVE MEAN RATINGS OF THE EVALUATED SHIRT GARMENTS PER SUBJECT

SHIRT MEAN RATINGS																		
	Subject 1		Subject 2		Subject 3		Subject 4		Subject 5		Subject 6		Subject 7		Subject 8		Subject 9	
EVALUATING STANDARDS	**SC**	**M**	**SC**	**M**	**SC**	**M**	**SC**	**M**	**SC**	**M**	**SC**	**M**	**SC**	**M**	**SC**	**M**	**SC**	**M**
1. Compatibility & ease	2	2	2.5	1.5	DOES NOT FIT		1.5	DOES NOT FIT	2	2.5	2.5	1	2.5	2	DOES NOT FIT		2	DOES NOT FIT
2. Garment rest	2.5	2	2	1.5			2		1.5	2	2.5	1	2.5	2			2.5	
3. Drape front garment	3	3	2.5	2			2		1.5	2	2.5	1.5	2	2			2.5	
4. Drape back garment	2.5	2.5	2	2			2		2	1.5	2.5	2.5	2	1.5			2.5	
5. Neckline collar	3	3	3	2			3		3	3	3	3	3	3			3	
6. Shoulders	2	2	2.5	1.5			2		3	3	2	2.5	3	2.5			3	
7. Armholes	1.5	2	1.5	2			2		2	1.5	1	1.5	2	1.5			2.5	
8. Sleeve length	2.5	1	2.5	1			2		2	1.5	2.5	2	2.5	1.5			2	
9. Sleeve biceps	2.5	1.5	2.5	1			1.5		2.5	1.5	2	1	2.5	1.5			1.5	
10. Sleeve elbow	2.5	2.5	2	1.5			2		2	2	2.5	1	3	2.5			2	
11. Sleeve wrist	3	3	3	2			2.5		3	3	3	2.5	3	3			2.5	
12. Ease bust	2.5	2.5	2.5	2			1.5		1	1.5	2	1.5	2	2.5			2	
13. Closure alignment	3	2.5	3	1.5			2.5		2	2	2	1.5	2	2.5			2	
14. Garment closure	2.5	2.5	2	2			1.5		1.5	1.5	1.5	1	3	2			2	
15. Hems & finishes	2.5	3	1.5	3			3		3	2.5	2.5	2	2.5	3			2.5	
16. Garment length	3	3	2.5	2			1.5		2.5	2	2.5	2.5	2.5	3			2.5	
17. Comfortability & movement	2.5	2	2.5	1.5			2		2	1.5	1.5	1	3	2			2	
18. Can the wearer sit?	3	2.5	3	2			3		2.5	2	3	1.5	3	2			2.5	
OVERALL MEAN RATINGS	**2.6**	**2.4**	**2.4**	**1.8**	**0.0**	**0.0**	**2.1**	**0.0**	**2.2**	**2.0**	**2.3**	**1.7**	**2.6**	**2.2**	**0.0**	**0.0**	**2.3**	**0.0**

*Evaluating scales: 3 = good quality of fit; 2 = moderate quality of fit; 1 = poor quality of fit
*SC = Size chart measurements; M = Mannequin measurements

TABLE 12: COMPARATIVE MEAN RATINGS OF THE EVALUATED TROUSER GARMENTS PER SUBJECT

TROUSER MEAN RATINGS																		
	Subject 1		Subject 2		Subject 3		Subject 4		Subject 5		Subject 6		Subject 7		Subject 8		Subject 9	
EVALUATING STANDARDS	**SC**	**M**	**SC**	**M**	**SC**	**M**	**SC**	**M**	**SC**	**M**	**SC**	**M**	**SC**	**M**	**SC**	**M**	**SC**	**M**
1.Compatibility & ease	2.5	1.5	2.5	2	2.5	2	2	1.5	2	2	2	2	2.5	1.5	2.5	2.5	2.5	1.5
2.Garment rest	3	1	3	2	2.5	1.5	2	1.5	2	2.5	2	2.5	2	2.5	2.5	2.5	2	1.5
3. Lower waist fit	3	3	3	3	3	2.5	2.5	2	2.5	2.5	2.5	3	2.5	3	3	3	2.5	2.5
4.Hip fit	2.5	1.5	2	2	2.5	2	3	2.5	3	2.5	3	2	2.5	2.5	3	3	2.5	1.5
5.Front crotch	2.5	1	2	2	2	2.5	1.5	1.5	2.5	2	2	2	2	1.5	2.5	1.5	2	1.5
6.Back buttocks	3	3	2	3	2	2.5	3	2	3	2.5	3	2.5	2	2.5	3	2.5	2	2
7.Seat drape	2.5	2	2	2.5	2	2	2.5	2	2.5	2.5	2.5	2.5	2.5	2.5	3	3	2	1.5
8.Thigh fit	2	2	2	2	3	2.5	2.5	2	2	2.5	2.5	2	2.5	2.5	2.5	2.5	2	1.5
9.Knees fit	2	2.5	2	3	3	2.5	2.5	3	3	2.5	3	2.5	2	2.5	3	3	2.5	2.5
10.Ankles fit	2	2	2	3	3	2.5	3	3	2	2.5	3	3	2	2.5	3	3	2.5	2.5
11.Inseam length	3	2.5	3	3	3	2	2.5	3	2.5	3	3	3	3	3	2.5	3	3	2.5
12.Outseam length	3	3	3	2.5	1.5	2	2.5	2.5	3	3	2.5	3	2.5	2.5	2.5	2.5	3	2
13.Hems & finishes	3	2.5	3	3	3	3	3	3	3	3	3	3	2.5	2	3	3	3	3
14.Ease for closure	2.5	2	3	3	3	2.5	3	2.5	1.5	3	3	2.5	2.5	3	3	2.5	3	2.5
15.Bottom of garment	2	1	2.5	3	3	3	3	3	2.5	2	3	3	1	1.5	3	3	3	3
16.Comfortability& movement	3	3	3	3	3	2	3	2.5	3	2.5	3	3	3	2	3	3	2.5	3
17.Sit	3	3	3	3	3	2.5	2.5	2	2	2	3	2	3	2.5	3	3	2.5	2.5
OVERALL MEAN RATINGS	**2.6**	**2.2**	**2.5**	**2.7**	**2.7**	**2.3**	**2.6**	**2.3**	**2.5**	**2.5**	**2.7**	**2.6**	**2.4**	**2.4**	**2.8**	**2.7**	**2.5**	**2.2**

* Evaluating scales: 3 = good quality of fit; 2 = moderate quality of fit; 1 = poor quality of fit
*SC = Size chart measurements; M = Mannequin measurements

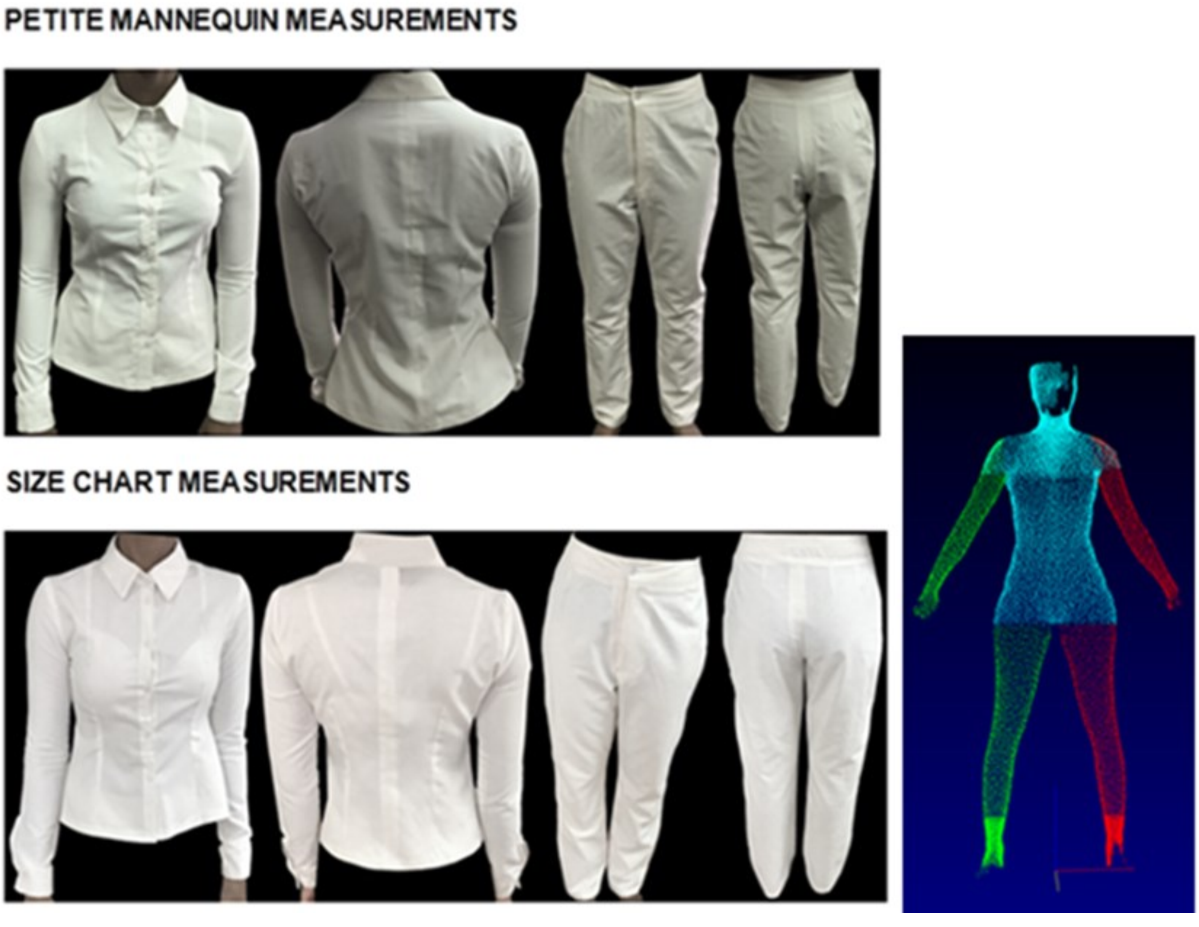

FIGURE 2: THE PROTOTYPE SHIRT AND TROUSER GARMENTS FITTED ON A PETITE SUBJECT AND THE SUBJECT'S 3D BODY SCAN

this study, garment manufacturers and designers should specifically target and cater for the pear body shape as a niche market by incorporating garment sizing, fit measurements and design styles that are suitable for the pear body shape profiles.

Limitations and further work

This petite sizing and fit study was exploratory and cannot be applied to the wider South African population as data were limited to a $(TC)^2$ NX16-3D full body scanned pear shaped petite women residing in the Gauteng. To further optimise the sizing system, analysis of a larger sample is suggested to improve the correlations between the primary and secondary body dimensions.

ACKNOWLEDGEMENTS

The authors wish to thank the National Research Fund (NRF) and the University of South Africa (UNISA) for providing funding for this study.

REFERENCES

Alexander, M., Connell, L.J. & Presley, A.B., 2005, ‘Clothing fit preferences of young female adult consumers’, *International Journal of Clothing Science and Technology*, 17(1),52-64.

Apeagyei, P.R., 2010, ‘Application of 3D full body scanning technology to human measurement for clothing Fit’. *International Journal of Digital Content Technology and its Applications*, 4(7), 58-68.

Bailey, C.S., 2010, ‘Petite women: The reflection of confidence for petite women through dress’, Baccalaureus Technologie Dissertation’, Cape Peninsula University, Cape Town.

Barona-Mcroberts, L., 2005, ‘Petite Women: Fit and body shape analysis’, Unpublished Masters thesis, Dept. of Human Ecology, Louisiana State University.

Bye, E., Labat, K.L. & Delong, M.R., 2006, ‘Analysis of body measurement systems for apparel’, *Clothing and Textiles Research Journal*, 24(2), 66-79.

Defty, A., 1988, *The fascinating art of creating patterns,* Penprint (PTY) LTD, Durban.

Gupta, D. & Gangadhar, B.R., 2004, ‘Communications: A statistical model for developing body size charts for garments’, *International Journal of Clothing,* 16(5), 458-469.

Kahn, T., 2008, ‘Survey will get the measure of us all, so we can dress comfortably’, *Business Day*, 11 February, p.1.

Kim, S., 1993, ‘Analysis of petite-sized women’s body proportions related to garment fit’, Doctorate Dissertation, University of Minnesota, United States.

Kim, Y., Song, H.K. & Ashdown, S.P., 2016, ‘Women’s petite and regular body measurements compared to current retail sizing conventions’, *International Journal of Clothing Science and Technology*, vol. 28, no. 1, pp.47 – 64.

Liechty, E.L., Rasband, J.A. & Pottberg-Steineckert, D.N., 2010, *Fitting and pattern alterations*. 2nd ed. Fairchild, New York.

Marshall, S., Jackson, H. & Stanley, M.S., 2012, *Individuality: in apparel selection and personal appearance*. 7th ed. Prentice Hall, New York.

Mbandazayo, S., Nkosi, N. & Mgwali, Y., 2014, ‘Vanity sizing, Have we shrunk or our clothes grown?’, *Zest*, 6 October, p.10.

Muthambi, A., 2012, ‘Proposed sizing for young South African women of African descent with triangular shaped bodies’, Masters Dissertation. University of Pretoria, Pretoria.

Ola-Afolayan, O. & Mastamet-Mason, A., 2013. ‘A customised size chart for the African pear-shaped plus-size South African women’, *2013 DEFSA Conference Proceedings*, Vaal University of Technology, September 11, 2013, pp. 202-210.

Pandarum, K. & Yu, W., 2015, ‘Garment sizing and fit’, in R. Nayak & R. Padhye (eds.), *Garment Manufacturing Technology*, pp. 187-195, Woodhead Publishing, United Kingdom.

Park, J., Nam, Y., Choi, K., Lee, Y. & Lee, K.H., 2009, ‘Apparel consumers’ type and their shopping characteristics’, *Journal of Fashion Marketing and Management*, 13(3), 372-393.

Petrova, A., 2007, ‘Creating sizing systems’, in Ashdown, S.P. (ed.), *Sizing in clothing: developing effective sizing systems for ready-to-*

wear clothing, pp. 64-70, Woodhead Publishing Limited, England.

Petrova, A. & Ashdown, S. P., 2008, 'Three-dimensional body scan data analysis body size and shape dependence of ease values for pants' fit', *Clothing and Textiles Research Journal*, 26 (3), 227-252.

Redmore, N., 2012, *Woven Apparel Fabrics. In: Woven Textiles: Principles, developments, and applications*, viewed 17 June 2016 from http://eprints.hud.ac.uk/20088/.

Sokhetye, P.N., 2016, 'Development of a jeans sizing system for young Black pear-shaped South African women', Masters Dissertation, Durban University of Technology, Durban.

South African National Standard, 2019, *Size designation of clothes- Part 1: Anthropometric definitions for body measurement*, (SANS 8559-1), South African Bureau of Standards, Pretoria.

Stamper, A.A., Sharp, S.H. & Donnell, L.B., 2005, *Evaluating Apparel Quality*. 2nd ed. Fairchild Fashion Group, New York.

Statistics South Africa 2014, *Statistical release P0302,* Mid-year population estimates, Pretoria.

Strydom, M., 2006, 'An evaluation of South African clothing related population measures and sizing systems', Masters Dissertation, University of Pretoria, Pretoria.

Trish Newbery Design., 2014, '*Calico fabric'*, viewed 5 May 2015, from http://www.trishnewbery.com/knowledge/fabric-fibres-textiles-and-print/fabric-header/fabric/calico-fabric/.

Winks, J.M., 1990, 'The development of standard sizing systems for clothes', Masters Dissertation, Port Elizabeth University, Port Elizabeth.

Zakaria, N., 2014, 'Body shape analysis and identification of key dimensions for apparel sizing systems', in D. Gupta & N. Zakaria (eds.), *Anthropometry, apparel sizing and design,* pp. 96-113, Woodhead Publishing, United Kingdom.