STATISTICAL MODELLING OF KEY BODY DIMENSIONS IN DEVELOPING THE SIZE CHART FOR THE SOUTH AFRICAN PEAR-SHAPED WOMEN

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ABSTRACT

Anthropometric body measurement is a crucial process in the development of size charts for garment manufacturing. Body measurements differ between specific population groups, and garments catering for different populations must be manufactured based upon accurate size charts informed by accurate body measurements for that population. Amongst population groups, the full-figured, pear-shaped South African woman is a unique identifiable body type. This body type is not adequately catered for in garment manufacturing, as it requires a unique configuration of garments with different sizes for the upper and lower torso. The relative absence of well-fitting garments for this body type necessitates taking body measurements in order to develop a size chart to inform design and manufacturing of garments.

The purpose of this paper is to develop a statistical model of key body dimensions (bust, waist and hip) to populate a size chart for the manufacturing of ready-to-wear garments for the full-figured, pear-shaped South African woman. A correlational research method using body measurements from purposively selected women of ages 25 to 55 years was carried out. After categorizing the height measurements into three groups, the means of body measurements for the medium height group were used to develop a size chart for sizes 16 to size 24, using principal component analysis (PCA) and least squares regression.

Results showed that the bust, waist and hip values highly contribute towards body type sizing. The bust and hip were highly correlated at R2=0.996 (99.6%), and the model predicted the true value of the hip at R2=0.993 (99.3%). Bust measurement positively correlated to the waist at 93.8%, and the model predicted the true value of the waist at R2=0.880 (88%). Bust dimension was significant in predicting the hip and waist dimensions. Variances among hip dimensions in the current sizing were in 4 to 6 cm intervals. Full-figured, pear-shaped figures present 5.5 to 7.5 cm values across the hip measurements.

In conclusion, findings of the simulated values for hip and waist at different sizes based on bust measurements suggest that the values obtained respectively were almost the same with measurements in the customised size chart developed in the study. This makes the model dependable, reliable and valid for the size chart determination targeting the full-figured, pear-shaped South African woman. It is recommended that the model be used for determining size charts for other body shapes.

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BACKGROUND

Anthropometric measurements are typically used for the development of garment sizing systems (Dunn, 2016; Gupta, 2014; Ola-Afolayan, 2019). Conceived as far back as 1940 in the UK by William Sheldon (Carter & Health, 1990) body type size charts are developed from varied statistical models and analyses and have been produced in other countries, such as in Germany (Jaradat, Dokookhaki, Pampin & Shirvany, 2019), India (Zakari & Gupta, 2014) and in the USA (Ashdown, 2014). Size charts reflect sizes and consumers′ body measurements for specific sizes used to manufacture ready-to-wear apparel with an acceptable quality of fit (Ola-Afolayan & Zwane, 2019).

These garment sizing systems cater to general population groupings and general categories of an idealised body type, with only a limited amount of body type variability provided for within these categories (Adamski, Makhanya, De Klerk & Mastamet-Mason, 2015; Ola-Afolayan & Mastamet-Mason, 2013; Ola-Afolayan & Zwane, 2019). The South African female full-figured, pear-shaped body type is an example of a unique identifiable body type that deviates substantially from the standard hourglass shape that forms the basis for garment sizing systems, and from the Western pear shape (Ola-Afolayan and Zwane, 2019) and is consequently not accommodated for by garments manufactured for the typical pear-shaped body type.

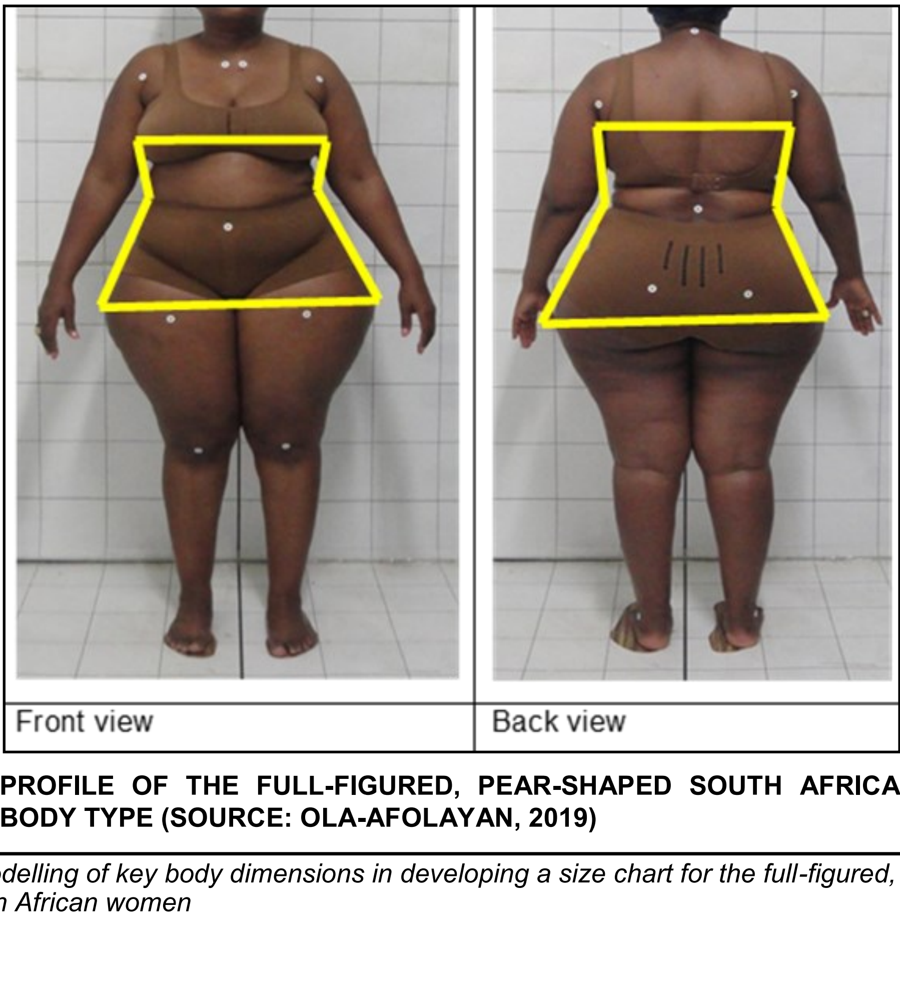

FIGURE 1: PROFILE OF THE FULL-FIGURED, PEAR-SHAPED SOUTH AFRICAN WOMAN BODY TYPE (SOURCE: OLA-AFOLAYAN, 2019)

This unique body type, illustrated in Figure 1, is prevalent among the South African and Southern African women of African descent, as exemplified by the historical figure of Saartjie Baartman (Ola-Afolayan, 2019; Mastamet-Mason, 2014). Makhanya, De Klerk, Adamski and Mastamet-Mason (2014) observed that approximately 60% of the university student population at the University of Pretoria in the north of the country possess these unique pear-shape characteristics.

South African ready-to-wear women's clothing is adapted from standardised sizing systems and specifies equilibrium at the upper and lower torso, which differs from the South African pear-shaped figure characterised by a lower torso (hip/thigh) that is larger than the upper torso, as revealed in Figure 1.

Women of this body-type face challenges in finding clothing that fits; they tend to be forced to purchase two different sizes for the upper and the lower torso in apparel suits or in coordinated garment styles. For example, a size 18 jacket or blouse must be combined with sizes 20, 22 or 24 for the skirt or pants, depending on the depth of the hip line and buttocks size of the individual (Ola-Afolayan, 2019). Apart from being obliged to purchase different sizes of garment pieces, these South African pear-shaped women must usually make alterations to the garments, particularly to the upper torso, so as to fit the figure appropriately (Ola-Afolayan & Mastamet-Mason, 2013; Zwane & Magagula, 2006).

This problem of a mismatch between apparel available in the market and actually existing body types, is exacerbated by the fact that South Africa does not have its own anthropometric database in the public domain. This is not unique to this instance of body type population: several researchers have conducted research relating to women's apparel sizing and fit in African countries, including Swaziland, Kenya, Nigeria and South Africa (Kasambala, Kempen & Pandarum, 2016; Kent-Onah & Sado, 2014; Makhanya *et al.*, 2015; Mastamet-Mason & De Klerk, 2012; Muthambi, De Klerk & Mastamet-Mason, 2015; Ola-Afolayan, Ola-Afolayan & Mastamet-Mason, 2013; Nkambule, 2012; Phasha, 2017; Zwane & Magagula, 2006). Muthambi *et al.* (2015) developed size specifications for young South African women of African descent and concluded women with the triangular body shape may keep experiencing fit problems with garment sizes based on the size specifications presently used in the South African garment industry. These scholars agree that the current sizing systems used in the manufacture of clothing for the African market are grossly inadequate in catering for the African female population with varied body shapes.

Most studies concur that sizing systems accommodating variances in body shapes and proportion associated with culture and age are rare (Makhanya, 2015). Demarcation of the market into niche segments of prevalent body shapes and creation of size charts dedicated to the niche markets could resolve fit problems instead of developing one sizing system to cater for varied body shapes and dimensions. Most of the research studies conducted in South Africa and on the Southern African population have been on general issues of size and fit, while none have concentrated on size chart development for the full-figured, pear-shaped South African women of African descent. There remains a gap in knowledge in the form of a publicly available anthropometric database and sizing system for the South African full-figured, pear-shaped woman. Therefore, this research is ground-breaking in developing a size chart for ready-to-wear garment manufacturing for this unique body type.

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BODY TYPE SIZING SYSTEMS

Statistical analyses used in the development of body type sizing systems range from simple mean measurements of the basic size with an addition or subtraction of the constant interval for different sizes, to complex mathematical formulas and advanced statistical analytical approaches.

Gupta and Gangadhar (2004) developed a statistical model for developing body size charts for women's garment manufacturing in India. From the anthropometric dataset, principal component analysis was carried out to reduce the number and to identify key variables that would form a size chart, and to determine the relationships between variables. They found that the bust for the upper and hip for the lower body measurements were the most critical dimensions affecting garment fit after validating the developed size chart. The statistical model showed experimentally that the bust should be used as a basis for apparel sizing because it gave lower aggregate losses in most categories when garments made from the model were fitted. The model further showed that girth measurements, namely bust and hip, were critical in determining body shapes. In Greece, Mpampa, Azariadis, and Sipidis (2010) derived a new method of developing sizing systems for the mass customisation of garments, characterised by six steps that involved linear regression analysis to develop all possible sizes using all primary and secondary dimensions. A measure of total satisfaction was used to measure fit. Xia and Istook (2017) proposed a method to create body sizing systems using natural log transformation, principle component analysis and multivariate linear regression. The output from the created method was then compared with the published standard for petite, regular and tall groups of individuals for 14 sizes. Results showed that the resultant method of generating a sizing system was reliable.

With regards to the statistical analyses or models in the South African context, Makhanya *et al.*, (2015) formulated a size chart from size 30 to 38 for key body measurements of female African and Caucasian body types, using the least squares regression analysis. They found that the key dimension (bust) was an independent variable that determined the change of the dependent variables (waist and hips). The bust estimated the regression equations for the waist and hips when calculated. The regression equation showed that the bust could be used to predict waist and hip values for different sizes.

PURPOSE OF THE RESEARCH

With few statistical models of anthropometric body type sizing systems generated in the African context, the purpose of this paper is to develop a statistical model of key body dimensions for a unique population of full-figured, pear-shaped South African women, that can be used to develop a size chart to inform design and manufacturing of ready-to-wear garments.

METHODOLOGY

Design

This research employs a quasi-experimental, quantitative research design. A quantitative approach was used to develop a statistical model of body dimensions from a sample of participants selected using non-probability and purposive sampling. The study incorporated correlational aspects where quantitative data were used to describe and measure the degree of association (or relationship) between two or more variables, with the produced statistical modelling being an end product (Babbie, 2010; Creswell, 2014).

Sampling

Identification of the precise target group defined by shared physical characteristics was necessary to develop a population-specific size chart (Babbie, 2010; Makhanya *et al.,* 2015; Muthambi, 2012; Ola-Afolayan, 2019; Pernecky, 2016; Zakaria & Gupta, 2014). Only full-figured women with pear body shape, aged between 25 and 55 years, were targeted. A total of 150 purposively selected women, as per the selection criteria were measured (Babbie, 2010; Pernecky, 2016), and 10 accepted to be photographed. The study was explained to the women as stipulated in the research ethics permit granted by the host institution (REC2013/05/006), and only willing participants were recruited from churches, malls and offices after their hip and bust measurements confirmed their eligibility (Ola-Afolayan & Mastamet-Mason, 2013).

Data Collection

Anthropometric data were collected from participants at a time and venue convenient for them, and after a follow-up call to ensure that they were still willing to take part in the study. Digital photographs of the eligible women, shown in Figure 1, were taken for triangulation purposes and for validation of the quantitative body measurement data. Trained research assistants alternated in taking the selected body measurements. To ensure reliability, all measurements were taken twice and called aloud for confirmation and recording. A non-stretchable metallic measuring tape, calibrated in centimetres, was used to take the two sets of measurements per participant to ensure reliable and valid body measurements (Creswell, 2013; Pedersen, 2014). The measuring techniques, procedures, and instruments used for taking measurements in the study were guided by international standards such as ISO/DIS8559-1 (2014), ISO/SABS (2012), and a procedure given by Stewart, Marfell-Jones and Deridder (2011).

Data Analysis

Descriptive statistics and multivariate analysis were used to categorise height measurements into three groups (tall, medium and short) and for key dimensions used to create the size chart. The size chart was developed from subjecting data on the three key girth measurements of bust, waist and hip to a series of statistical analyses ranging from descriptive analyses, multivariate analysis, and principal component analysis (Ola-Afolayan, 2019).

Principle component analysis was utilised in order to identity the key body dimensions that would contribute to the size chart and statistical model (Gupta and Gangadhar, 2004). The statistical model was based on mean scores of bust, waist and hip dimensions, formulated using linear regression analysis to predict and examine relationships between the bust, which

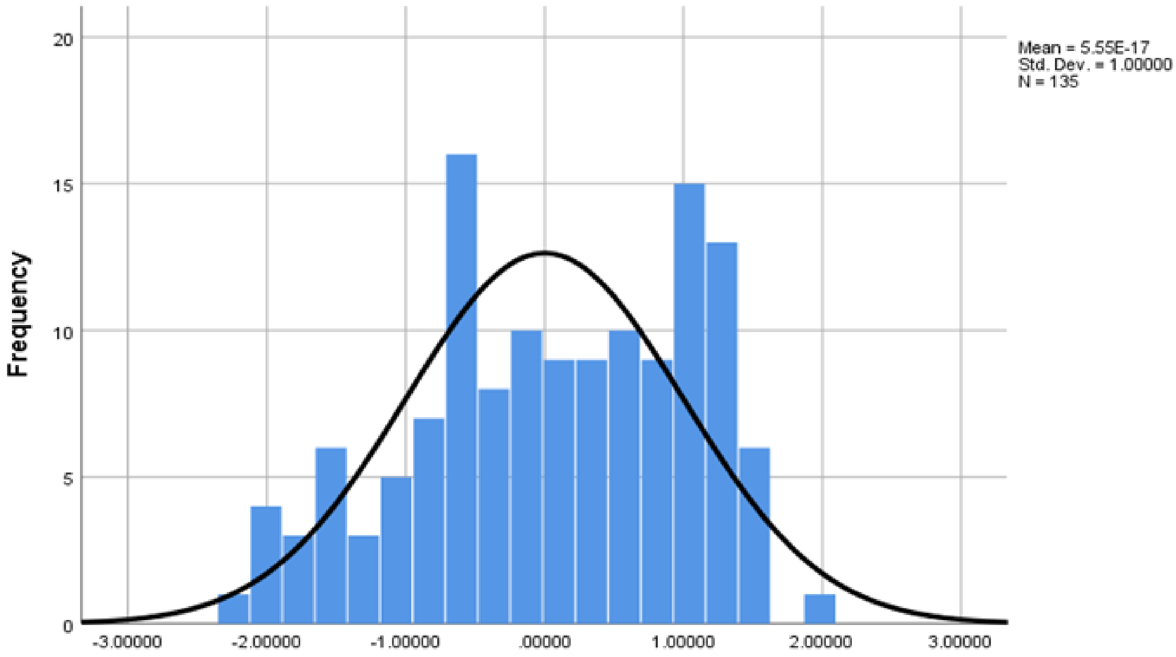

FIGURE 2: NORMALISED ANALYSIS OF DATA SET N=135

is the independent variable in this study, and the waist and hip measurements as dependent variables (Mpampa *et al.,* 2010).

A regression analysis was used to predict hip and the waist measurements using the bust dimension. This was a slightly modified version used by Makhanya *et al.,* (2015) and Adu-Boakye, Power, Wallace and Chen (2012). The regression model ($Y = a_0 + a_1X + e$), was used, where Y is the mean value of the unknown estimated value of the dependent variables (hip or waist measurement), X is the bust measurement at varying sizes of the size chart denoting the independent variable, a_0 is the intercept of the regression line, a_1 is the slope coefficient of the regression line, and e is the error term that becomes zero if the data are normally distributed. The intercept remains constant for any given straight line and represents the value of the waist and hips when the bust has a value of zero (0 cm) and e is the standard error in the equation or residual term (Adu-Boakye *et al*., 2012). The Slopes (a_1) and the intercepts (a_0) were computed in SPSS version 25.0.

RESULTS AND DISCUSSION

Age distribution

The 150 participants aged 25 to 55 years were relatively evenly distributed by age. The largest category was 41-45 years (20.7%), followed by 46-50 years (19.3%), 31-35 years (18.7%), 36-40 years (15.3%) and ≤ 30 years (14.7%). The least represented age group was 51-55 years at 11.3%. The sample is representative of the wider SA female population of key body dimensions for this population for the ages 25 to 55.

Normalisation of data

All the extracted body measurements were analysed using multivariate analysis after which, the resulting distribution curve appeared skewed towards the left side. It was therefore necessary to normalise the distribution, as seen in Figure 2, to avoid potential exaggerated effects on standard deviation and other statistical measures which would ultimately affect the quality of the model (Mehmet, Mustafa & Suphi, 2018). Outliers in the sample were detected using the standardised Z-test (Mehmet *et al.,* 2018). The skewness towards the left side of the distribution, at 4.0, was well over the scale of below +3 and above -3 z-score values criteria at

TABLE 1: PRINCIPAL COMPONENT ANALYSIS

Total variance explained				
Initial Eigenvalues				
Component		**Total**	**% of variance**	**Cumulative %**
Rescaled	1	1.857	51.806	51.806
	2	1.003	27.981	79.787
	3	0.341	9.540	89.327
	4	0.157	4.399	93.727
	5	0.050	1.406	95.132

All measurements are in centimetres. Extraction method used is Principal Component Analysis

a 95% confidence interval. There were 15 participants who formed the outliers in the sample data, representing 10% of participants. These were removed from the sample and the remaining 135 ensured normalisations of the distribution.

The height categories within various sizes of the remaining 135 produced a normal distribution curve, indicating that the majority (87.4%) were in the “medium height” category, while the smaller groups fell into the “short height” and “tall height” categories, at 5.9% and 6.7% respectively. The results showed that the pear-shaped South African women are a medium height of between 169cm – 175cm. The findings of this research are corroborated by Makhanya *et al.,* (2014) who found a similar height pattern for the majority of their participants being in the “medium height” (87.4%) category even though the participants were in a smaller size range with significantly different central tendency values. The measurements of women in the medium height category were used for the predictions in sizes 16 to 24 in line with the findings of other studies on developing size charts for apparel (Adu-Boakye *et al.,* 2012; Gupta & Gangadhar, 2004; Makhanya *et al.,* 2015).

Principal Component Analysis

The principal component analysis method used in analysis of the covariance matrix by rescaling the rotated component matrix shows two major principal components, as shown in Table 1.

Principal component 1 (girth measurements) has the highest loadings (large co-efficient of eigenvalues) on all girth-related measurements, i.e. bust girth, waist girth, hip girth (broadest point), neck base girth, armscye circumference, upper arm girth, elbow girth, under-bust girth, lower waist girth, upper hip girths, hip girth (normal), widest thigh girth, across back shoulders, and across chest. Principal component 2 (vertical measurements) also has the next highest loadings on lower and upper body related measurements, i.e., apex to shoulder, nape to ground (cervical height standing), armscye to ground, natural waist to ground, knee height (mid-patella), shoulder to waist, scye/armhole depth, body rise, underarm landmark (side seam).

When analysing a covariance matrix, the initial Eigenvalues are the same across the raw and rescaled solution. Table 1 shows that component 1 (horizontal) body measurements highly contributed towards the formation of the size chart by eigenvalue 1.857 at 51.8%. Therefore, the three key girth measurements of bust, waist and hip highly contributed towards the formation of the size chart. Component 2 (vertical) body measurements were next in contributing towards the formation of the size chart by Eigenvalue of 1.003 at 28%. Results are congruent with Gupta and Gangdhar (2004) who also found girth measurements namely bust and hip were critical in determining body shapes, followed by height measurements.

Regression Modelling

The regression modelling was performed to evaluate drop values, or the hip, waist and bust measurements for varying sizes. These measurements were expressed as $Y_1 = a_0 + a_1X + e$, where Y_1=hip, X=bust, Y_2=waist and e is a zero. The estimated model of hip=35.79+0.939 (bust), reveals that bust and hip are positively correlated. This therefore shows that a unit change in the bust size of a pear-shaped South African woman results in a corresponding increase of 35.79 in the key hip dimension. The slope, as applied to garment sizing, represents the estimated rate of change (increase) by 0.939

TABLE 2: REGRESSION COEFFICIENT CONSTANT CALCULATIONS FOR THE HIP (MODEL 1)

Variable	Coeff. (B)	Std. Error	T	Sig.	Remark
(Constant)	35.79	5.011	7.142	0.006	
Bust	.939	.046	20.245	.00005*	Significant
R	R Square	Adjusted R Square	R Square Change	F Change	Sig.
0.996[a]	0.993	0.990	0.993	466.696	0.00005*

* All measurements are in centimetres, at 5% significance level

TABLE 3: PREDICTION OF HIP MEASUREMENT FROM SAMPLED BUST SIZES

Size	Bust mean measurement	Predicted Hip=36.79+0.939 bust	Hip measurement in new size-chart
16	98	129	128
18	103	133	133
20	108	136	138
22	113	143	143
24	119	149	148

* All measurements are in centimetres, mean value of bust measurement used to predict hip measurement for the respective sizes

cm for a unit change in bust, holding other factors constant (see Table 2).

The intercept remains constant for any given value of hips: when the bust value is zero (0 cm), the hip remains 35.79cm. Thus, the estimated model for hip prediction based on the known bust measurement is defined as hip=35.79+0.939 (bust). Hip and bust were found to be highly correlated at 0.996 (99.6%). Furthermore, the model fits well because the F-statistic (466.696) is associated with a highly significant p-value of 0.00005, tested at a 5% significance level. This confirms the strong evidence that bust measurement is critical and significant in predicting the size of the hip measurement (Gupta and Gangdhar, 2004).

The coefficient of determination of the model for the hip based on the bust measurement is 99.3% fitted. Adjusted R-square means that the bust explains 99% of the variation in hip measurement from the proposed size chart for sizes 16, 20 and 24, as shown in Table 2.

Regression analysis can apply to other body shapes using the bust measurement to predict the hip and waist measurements for a size chart. The bust measurement obtained for each size in the medium range of the size chart was used to predict hip measurements, as shown in Table 3. The proposed hip measurements were from the developed size chart by Ola-Afolayan (2019) for full-figured, pear-shaped South African women. The difference between the predicted hip measurements and the proposed hip measurements was very minimal. This is shown on sizes 16 and 24, where the difference between the predicted (129cm) (149cm) and proposed (128cm) (148cm) hip measurements is positive one, respectively. For size 20, the difference is negative two between the predicted (136cm) and proposed (138cm) hip measurements.

The estimated model of waist=-55.985+1.365 (bust), reveals that bust and waist are positively correlated at 93.8%. This therefore shows that the bust measurement is decreased by 55.98 to get the waist measurement. The slope, as applied to garment sizing, represents the estimated rate of change (increase) by 1.365 cm for a unit change in bust holding other factors constant (see Table 4).

The intercept remains constant for any given value of waist when the bust value is zero (0 cm), the waist remains -55.985. Thus, the estimated model for waist prediction based on the known bust measurement is defined as Waist=-55.985+1.365(bust). Waist and bust were found to be positively correlated at 93.8%. Furthermore, the model fits well because the F-statistic (22.031) is associated with a significant

TABLE 4: REGRESSION COEFFICIENT CONSTANT CALCULATIONS FOR THE WAIST (MODEL 2)

Variable	Coeff. (B)	Std. Error	t	Sig.	Remark
(Constant)	-55.985	32.920	-1.701	0.188	
Bust	1.365	0.305	4.482	0.021*	Significant
R	R Square	Adjusted R Square	R Square Change	F Change	Sig.
0.938[a]	0.880	0.840	0.880	22.031	0.021*

* All measurements are in centimetres, at 5% significance level

TABLE 5: PREDICTED WAIST MEASUREMENT FROM SAMPLED BUST SIZES

Size	Bust mean measurement	Predicted Waist = -55.985+1.36 bust	Waist measurement in new size-chart
16	98	80	83
18	103	87	87
20	108	91	91
22	113	101	95
24	119	109	99

* All measurements are in centimetres. Mean value of bust measurement used to predict hip measurement for the respective sizes

TABLE 6: SIZE CHART OF KEY BODY DIMENSIONS OF THE FULL-FIGURED, PEAR-SHAPED SOUTH AFRICAN WOMAN

Size range	16/46 – 24/54									
Height category	Medium height									
Size	16 P. m/m	16 C. m/m	18 P. m/m	18 C. m/m	20 P. m/m	20 C. m/m	22 P. m/m	22 C. m/m	24 P. m/m	24 C. m/m
Bust	98	96	103	100	108	104	113	110	119	116
Waist	83	80	87	84	91	88	95	94	99	100
Hips	128	104	133	108	138	112	143	117	148	122

* All measurements are in centimetres. Mean value of bust measurement used to predict hip measurement for the respective sizes P. m/m – proposed body measurement, C. m/m – current body measurement

p-value of 0.021, tested at a significance level of 5%. This confirms that bust measurement is significant in predicting the size of the waist measurement.

The coefficient of predicting the model for waist based on the bust measurement is 88%. Adjusted R-square value means that the bust explains 84% of the variation in waist measurement from the proposed size chart for sizes 16, 22 and 24, as shown in Table 4 and Table 5. Although the correlation is weaker than the bust and the hip relationship, 88% is still strong, as any correlation above 60% is considered sufficient (Gupta & Gangabhar, 2004).

The bust measurement for each size was used to predict the waist measurement, as shown in Table 5. There was variability in predicted and proposed waist measurements for sizes 16, 22 and 24. The slope (1.365) represents the estimated rate of change (increase of 1.36cm) for the bust for every 1 cm correspondent change in the waist. Again, the predicted waist measurements were produced from the regression model, and the proposed waist measurements were from the developed size chart by Ola-Afolayan (2019).

The difference between the predicted waist measurements and the proposed waist measurements was minimal. For size 16 the difference between the predicted (80cm) and proposed (83cm) waist body measurements is negative three. For size 22, a positive six difference is shown between the predicted waist (101cm) and the proposed (95cm) waist measurements. A larger difference of positive ten is observed for size 24, where the predicted waist value is 109cm and the proposed waist value is 99cm. This may be attributable to the variability in the waist measurements of participants in the study.

The customised size chart for the South African pear-shaped women of African descent is presented in Table 6.

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CONCLUSIONS AND RECOMMENDATIONS

The two models developed in this research are dependable and reliable for the determination of the specified three key girth body dimensions (bust, waist and hips) within the size chart for the full-figured, pear-shaped South African woman. The models substantiate that the bust measurement is critical and significant in determining waist and hip body size measurements, and that the bust measurement may be used in predicting sizes of apparel by consumers, as also confirmed by Makhanya *et al* (2015) and Gupta and Gangadhar (2004).

The extent of the difference between sizes in the hip dimensions in this model and in the standard pear-shaped women's body measurement emphasises the vast dissimilarity between the shapes of the South African pear-shaped figure and the standard "ideal" body shape, or the western pear-shaped figure. These results are consistent with those of Makhanya *et al.* (2014), Muthambi (2015), Ola-Afolayan and Mastamet-Mason (2013) and Ola-Afolayan and Zwane (2019) and confirm that a size chart based on the standard "ideal" body shape is incapable of providing the full-figured, pear-shaped South African woman with a good fit of apparel.

The limitations of this study merit further research on other body height or width measurements to identify significant relationships with other measurements for all varieties of clothing not catered for in this study. The key measurements studied are useful in the selection of a limited array of clothing, such as skirts and tunic fitted dresses. Other clothing items would require a wider scope of added key body dimensions not included in this paper.

The information in this study offers direction for successive studies on the need to focus on the vital and key body dimensions for the development of size charts, considerably reducing the cost of such investigations. It is recommended that fit tests using size chart body measurements be done before considering that the charts could be used by various stakeholders in the fashion industry's supply chain (manufacturers, retailers and fashion consumers) for appropriate clothing manufacturing, labelling and distribution catering for the full-figured, pear-shaped South African woman.

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