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Body shapes and apparel fit for overweight and obese women in the US: the implications of current sizing system

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Abstract

Purpose – The purpose of this study was to categorize the whole body shapes of overweight and obese females in the US and examine apparel fit based on the current ASTM sizing standards related to the body shapes categorized.

Design/methodology/approach – Body scan data from 2,672 subjects were used. To categorize their whole body shapes using 97 body measurements, principal component analysis with varimax rotation, a hierarchical cluster analysis and K-means cluster analysis were used. To compare the ASTM sizing standards for plus sizes (curvy and straight) and missy sizes (curvy and straight), five body parts (bust, under bust, waist, top hip, hip) using the formula for fit tolerance (measurement plus half of the interval) were compared with the ASTM sizing standards to determine the size appropriate for each body part.

Findings – Five whole body shapes among overweight and obese females in the US were categorized: Rectangle-curvy; parallelogram-moderately curvy; parallelogram-hip tilt; inverted trapezoid-moderately curvy and inverted trapezoid-hip tilt. When the body measurements in each body shape were compared with the current ASTM sizing systems for both misses and plus sizes, four-fifths or more of overweight and obese female adults in the US would find it difficult to obtain a perfect fit for both tops and bottoms.

Originality/value – Identifying whole body shapes among overweight and obese women in the US contributes significantly, as it will help apparel companies that target the markets of larger women develop a new sizing system. This study is the first attempt to analyze fit by comparing the ASTM sizing charts with body measurements in each body shape group. Further, the study contributes to the body-related literature by filling gaps in missing whole BS categories among overweight and obese females.

Keywords 3D body scanning, Body shape, Apparel fit, Apparel sizing

Paper type Research paper

Introduction

The number of Americans who are obese and overweight has increased alarmingly, such that approximately 39.8% of adults are obese and 31.8% are overweight (Center for Disease Control and Prevention, 2016). Excessive weight and obesity are defined as "…abnormal and excessive fat accumulation that presents a risk to health" (WHO.int, 2020). The body mass index (BMI), which is an important indicator of chronic diseases, including diabetes, cardiovascular diseases and cancer (WHO.int, 2020), is used to measure whether one is overweight (BMI of 25 and below 30) or obese (BMI of 30 and above).

Excessive weight causes significant body changes and clothing fit problems for overweight and obese (OWOB) women for two reasons: (1) The amounts of fat deposited on particular body areas (e.g. bust, waist, thigh) are significantly higher than on non-OWOB women (Johnston *et al.*, 1988), and (2) although plus-size women's clothing is a $21 billion

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industry, few apparel companies focus on plus-sized female consumers (Meyersohn, 2018) despite the significantly large number of OWOB adults in the US thus, exploring the characteristics of OWOB adults' body shapes would help improve the sizing system and new product development process for larger women.

Some studies have shown the relations between excessive fat accumulation and changes in body geometry and posture (Berriganet *et al.*, 2006; Fabris De Souza *et al.*, 2005). Berriganet *et al.* (2006) found that obesity caused postural instability that constrained goal-directed movements and daily activities, such as "...upper limb movements performed from an upright standing position" (p. 1,750). Further, morbidly obese individuals usually have scoliosis and increased thoracic kyphosis and hyperlordosis, which cause anteversion of the head. Given the changes in body shapes (BSs) fat accumulation causes, OWOB female consumers' BSs differ from the BS that has been used to create the sizing standard in the fashion industry. However, there is the lack of understanding of OWOB female' anthropometric characteristics and BSs (Park and Park, 2013).

With limited studies on fit problems in clothing in general among larger women, researchers focused on investigating fit problems in specific clothing categories, such as intimate wear (Bishop *et al.*, 2018), swimwear (Christel and O'Donnell, 2016) and exercise apparel (Greenleaf *et al.*, 2020). OWOB females' inability to find clothing that fits well often makes them feel they are socially inferior because of the unequal accessibility to clothing that fits well (Bishop *et al.*, 2018), and thus they may feel frustrated and rejected by the fashion industry (Otieno *et al.*, 2005; Scaraboto and Fischer, 2013). Furthermore, individuals who experienced poor fit tend to have more negative body image and greater body dissatisfaction than those with greater fit satisfaction (LaBat and DeLong, 1990). Hence, apparel companies have considered improving their size standards that affect OWOB female consumers' self-identity and social status (Bishop *et al.*, 2018). For example, leading retailers (e.g. Walmart, Nike and Adidas) developed and sold plus-sized lines for size inclusivity (Ashley, 2020). However, because there have been limited studies attempting to understand BSs related fit problems in clothing in general among larger women, improving fit for OWOB women has not been an easy task for apparel companies. This, a continuous effort on the part of fashion companies, is needed to extend beyond size inclusivity by attempting to understand larger BSs.

To help fashion companies provide their OWOB female consumers with improved fit and sizes, identifying their whole BS considering upper and lower bodies together would be an important step to determine the reasons why they experience ill-fitting clothes. OWOB female consumers' difficulties with fit and size may be attributable to the fact that their BSs differ from the standardized BS used to make sizing charts in the current fashion industry (Sokolowski *et al.*, 2020). However, researchers have conducted several studies to understand the BSs of females in the US (Song and Ashdown, 2011) and larger females in South Korea (Park and Park, 2013). Song and Ashdown (2011) provided data on a wide BMI range of women's body measurements between BMIs of 16.2 and 34.1 (aged between 18 and 35) that were included to identify the lower BS of women. Thus, their results cannot be applicable to OWOB women's BSs because they included underweighted and normal weighted women. Further, a person's whole body is not limited to the lower body, but consists of the upper and lower bodies combined. For example, a woman can have a curvy lower body with a thin upper body, while another can have both a curvy lower and upper body. These two should not be categorized into the same whole BS. Although Park and Park (2013) categorized BSs among larger women in South Korea, their results also cannot be generalized for use with OWOB women in the US because females' body proportions are different between the US and South Korea (Lee *et al.*, 2007). To address these gaps, the purpose of this study was to categorize the whole BSs of OWOB females in the US and examine apparel fit based on the current ASTM sizing standards related to the BSs categorized. In the initial stage of identifying the whole BS, it is necessary to include OWOB women in a wide age range, from 18 to 55 years. Thus, we used the SizeUSA database, "…a large representative database of measurements of US women" (Song and Ashdown, 2011, p. 916), and included data on OWOB women with a BMI of 25 or over aged between 18 and 55 years to address the following two research questions:

RQ1. What are the representative whole BSs among OWOB females in the US?

RQ2. How accurately do the current ASTM sizing standards reflect the whole BSs identified among OWOB females in the US?

This study's implications include the fact that understanding the whole BSs among OWOB female consumers will help fashion companies update sizing charts to meet their customers' needs for various BSs not limited to hourglass and standardized BSs among consumers with normal weight. Consequently, this will benefit both OWOB female consumers and fashion companies: Consumers may have fewer fit and size problems that cause them to feel socially inferior, while apparel companies will receive economic benefits with fewer returns and exchanges caused by problems with ill-fitting clothes (Faust and Carrier, 2010).

Literature review

Overweight, obese and fat distribution

There are two types of fat distribution in obesity: The android and gynoid shapes (Vague, 1956). The android shape is referred to as upper or central obesity (Lefebvre *et al.*, 1997). This shape has a waist-to-hip ratio (WHR; an indicator used to measure fat distribution around the waist, Ashwell, 2009) greater than 0.8 with excessive subcutaneous fat accumulated particularly on the trunk. The gynoid shape is defined as gluteo-femoral obesity, in which one's WHR is less than 0.8 with excessive fat in the abdominal visceral area. It is also referred to as gynoid obesity or lower obesity and is observed primarily in women.

Ashwell (2009) introduced the Ashwell® Shape Chart that shows the relation between waist measurements and height and categorizes them into four categories depending upon the level of health risk. If the WHtR is less than 0.4, it is considered the brown "chili" category. If the WHtR is between 0.4 and 0.5, it is in the green "pear" category. If the individual's WHtR is between 0.5 and 0.6, it is in the yellow "pear-apple" category. If the individual's WHtR is greater than 0.6, he/she is in the red "apple" category.

Body shape categorization and 3D body scanning technology

Connell *et al.* (2006) developed the Body Shape Assessment Scale (BSAS©), which included female's whole BS from the front view and side view. Female's whole BS from the front view is categorized into five shapes based on shoulder (the end of shoulders), waist and the widest points between the waist and crotch, the circle, pear, rectangle, inverted triangle and hourglass measured on a 1–5 scale between two BSs.

To evaluate female's whole BS from the side view of the body, bust shapes (l or r), front torso shapes (b, B or D) between the bust and below waist, buttocks shapes (Low Hook or Even Arch) and back shape (upper back, middle back and lower back) are rated from 1, very flat, to 5, very prominent (or full for back shape: Connell *et al.*, 2006). In addition, Connell *et al.* (2006) considered posture to be one of the important scales in the BSAS©. They revised Douty's Posture Scale (Jones, 1972) based on 3D body scan data: Aligned, forward alignment and compensating alignment.

August (1981) also described two variations in bust shapes, either flat ("*l*" shape) or prominent ("*r*" shape) and two variations in buttocks shape, "Low Hook" and "Even Arch." The Low Hook shape has a flat line from the waist until it curves under the crotch line, while the Even Arch shape has a symmetrically rounded line from immediately below the waistline to the crotch line. In the back shape, August (1981) noted that back curvature from below the neck to immediately above the waist depends upon where the curvature is concentrated, in the upper back (from below the neck to the top of the arm), middle back (primary fullness in the curvature up to the mid arm level) and lower back (primary fullness below the underarm).

Although August (1981) and Connell *et al.* (2006) have defined the body's silhouette and profile for the separate parts of the body, the methods used to categorize BSs are difficult to apply to a traditional pattern-making method because separated body projections depending on the views can result in several possible BSs (Song and Ashdown, 2011). For example, females with "*r*" bust shape can have three different buttocks shapes.

To overcome the issues, Song and Ashdown (2011) developed a new and more holistic method than others to categorize BSs, which combined front and side view of body using body measurements that can directly apply to the pattern-making process. Using body measurements extracted from 3D body scanning technology, they categorized female's lower BSs among 18–35-year-old females with a BMI of 34.1 or less. They used principal component analysis (PCA) to reduce the number of factors that used to categorize BSs by combining similar body measurements into the same factor of a principal component. The identified five factors of principal components were two silhouettes (waist to top hip and top hip to full hip silhouette), two prominences in the buttocks and abdomen areas and the slope from the abdomen point to front hip point. The researchers found three lower BSs among 2,488 young female participants, straight, tilted and curvy (Song and Ashdown, 2011).

Song *et al.* (2021) recently categorized four upper body shapes using 3D body scan data among a total of 423 females (ages between 40 and 69) in the United States. The researchers followed the same procedures of body shape categorization that were used in the previous study (Song and Ashdown, 2011), which included PCA and cluster analysis. There were eight factors that determined the aged females' upper body shapes: acromial inclination, upper body slope, neck inclination, waist depth, shoulder angle, overall body length, upper back curvature and back protrusion height (Song *et al.*, 2021).

Daniell *et al.* (2014) also used 3D body scans (i.e. the Vitus Smart whole-body scanner by Human Solutions) to examine the relations between body volumes and BMI among female and male adults. Particularly for overweight and obese female adults, as BMI increased, the volumes of the pelvic (stomach above waist line in our study) and abdominal areas (from waist line to crotch in our study) increased at a significantly greater rate than did the whole body volume. For females with a BMI of up to approximately 32, the body volume in the abdominal areas increased significantly and resulted in a pear-shaped body, while for females with a BMI of above approximately 33, the body volume in the stomach areas increased sharply and resulted in an apple shape (Daniell *et al.*, 2014).

There were two studies on the whole BS categorization among South Korean women. Park and Park (2013) used 3D body scan data from 1,327 females in South Korea to categorize the whole BS among Korean OWOB women whose aged between 10s and 60s. Through the factor analysis and cluster analysis, there were four BSs: (1) Large torso and below-average shoulder width, (2) wide shoulder and below-average lower body, (3) small torso and large lower body and (4) small figure. Yu and Kim (2020) recently analyzed 3D anthropometric characteristics to categorize BSs among middle-aged women aged 40 to 59 ($n = 302$) with normal weight range (not including overweight and obese) in South Korea.

Although there has been a study on the whole BS categorization among larger women (Park and Park, 2013) and women with normal weight range (Yu and Kim, 2020) in South Korea, their results regarding the whole BSs cannot be generalized for OWOB women in the US To address the knowledge gap, we categorized the whole BSs and examined how accurately the current ASTM sizing standards meet the categorized whole BSs for OWOB women in the US.

Methods

The SizeUSA data are a nationwide anthropometric data in the US ([TC]2, n.d.), females with a BMI of 25 or higher and aged between 18 and 55 were used in this study. The ages of a total of 2,672 subjects were categorized into four groups (18–25 years old: 748, 28%; 26–35 years old: 422, 15.8%; 36–45 years old: 821, 30.7% and 46–55 years old: 681, 25.5%). Approximately one-half (1,188, 44.5%) were non-Hispanic Caucasians, followed by non-Hispanic African Americans (679, 25.4%), Mexican Hispanics (241, 9.0%), others (226, 8.5%), non-Mexican Hispanics (217, 8.1%) and Asians (121, 4.5%). The participants' BMI ranged from 25.01 to 69.97. A total of 1401 (52.4%) were overweight (BMI of 25 to <30) and 1,271 (47.6%) were obese (BMI of 30 or higher).

We followed Park and Park (2013) and Song and Ashdown (2011)'s study in the whole BS categorization process (RQ1). In addition to the list of body measurements, the body scan data in a.rbd format provided with the SizeUSA data were used to extract additional body measurements (i.e. width, and front and back points from body's side view to calculate depths) using the [TC]2 software. Following the previous studies (Park and Park, 2013; Song and Ashdown, 2011), a total of 97 body measurements were included initially to select shape-defining measurements, including 58 raw body measurements (i.e. full girth, front/back arc, width, full depth, length and height) and 39 drop values between the raw body measurements (i.e. drop values for girth, front/back arc, width and depth). For example, the depth drop values were calculated based on the raw measurements and the differences between the side seam depth (formula by Song and Ashdown, 2011) and front and back depths at the bust, waist, abdomen and hip levels. In addition, the back arc at each body level was obtained by subtracting the front arc from the full girth. Through bivariate correlations, 13 measurements (4 raw measurements and 9 drop values) related to BSs were identified regardless of body size, which had significantly low correlations with each other. After deleting six measurements that had no significant correlations with weight, all of the raw measurements showed significant, low correlations between each factor and weight that ranged from −0.29 to 0.22. To reduce the number of variables and combine similar variables into appropriate dimensions, PCA with varimax rotation (Hair *et al.*, 1995) was used. Any items loadings less than 0.5 and with multiple loadings on two or more variables were removed (Hair *et al.*, 1995). Based on the variables identified from PCA, a hierarchical cluster analysis with the Ward's method and K-means cluster analysis were conducted to specify the possible number of BSs for the OWOB women. To verify differences from one another in the categorized BS, a one-way analysis of variance (ANOVA) with post-hoc multiple comparison tests were employed to compare the mean value of each cluster that represents the BS. Then, the whole BSs identified for the OWOB women were compared among the different ages, ethnicities and BMI groups using a cross-tabulation analysis with chi-square test.

To define and name each categorized BS, we visually assessed the whole BSs using CLO software. Through CLO software, a virtual body model for each BS was created to evaluate the whole BS visually. Further, Adobe Illustrator was used to draw the lines for front and side body silhouettes (black lines shown in Figure 1) based upon the width and depth measurements for the bust, waist, top hip and hip areas. For the front body silhouette, we used width measurements for the bust, waist, top hip and hip areas while depth measurements for the four areas were used to draw the side body silhouette. After overlapping the virtual body model and the drawn silhouettes, the whole BSs were defined and named, which can support the differences in the identified whole BSs based on the statistical analyses in this study.

To identify a perfect fit in the sizing system within each BS group (RQ2), both ASTM sizing standards for plus sizes for curvy and straight (ASTM D6960/D6960M-16) (ASTM International, 2016) and misses sizes for curvy and straight (ASTM D5585-11) (ASTM International, 2012) were used for five body parts (bust, under bust, waist, top hip,

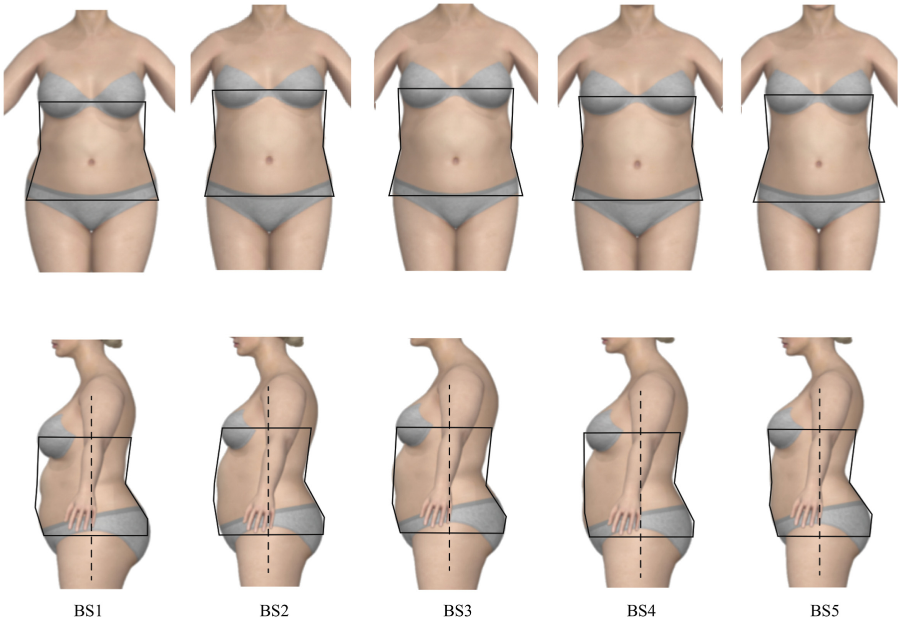

Figure 1.
Five whole body shapes

hip). The formula for fit tolerance (measurement plus half of the interval) was used to determine the size appropriate for each body part (Simmons *et al.*, 2004). The perfect fit was determined separately for tops and bottoms when three related body measurements (i.e. bust, under bust and waist for tops, waist, top hip and hip for bottoms) were consistent with the ASTM sizing standards. Thereafter, values of perfect fit for tops (bust, under bust and waist) and bottoms (waist, top hip and hip) in each size standard were obtained: For tops and bottoms, "0" was recorded when there were no size differences among all three parts, which refers to the perfect fit. Otherwise, if there were size differences in at least one area for tops and bottoms, "1" was recorded as fit problems. When a female's body did not fall within the range of sizing standard, "2" was coded to indicate "not applicable (NA)". Then, for each BS group, we calculated frequencies and percentages of the values of the perfect fit in each size standard.

Results

Principal component analysis

Through multiple PCA with 13 measurements, three variables that were highly correlated were deleted. A total of eight drop values and two raw measurements (buttocks angle, bust front depth and bust back depth) was found to be useful to categorize the OWOB female participants' BSs. As shown in Table 1, five PCs with eigenvalues greater than 1.0 that explained 76.3% of the variation in the 10 variables were extracted. The PCs were as follows: PC1 – Waist to hip silhouette and buttocks prominence; PC2 – Bust prominence; PC3 – Bust to waist back silhouette; PC4 – Back curvature (outward curvature of upper back and inward curvature of lower back) and PC5 – Abdomen prominence.

As Table 2 shows, PC1 had high loadings with three drop values, back arc: hip-top hip and width: hip-waist, and a value of buttocks angle. PC2 was correlated highly with two drop values, front arc: bust-waist and front depth: bust-waist. PC3 had a high correlation with two back arc drop values (bust-waist and bust-under bust). PC4 had high loadings with two values of back length from neck to waist with/wjthout bumps. PC5 had a high loading with a drop value of front depth: abdomen-waist. Analysis of the five variables showed that five PCs with eigenvalues of 1.0 and greater of 10 variables: PC1 = 23.37%; PC2 = 16.20%; PC3 = 13.24%; PC4 = 12.48% and PC5 = 11.02%, explained 76.30% of the variations. The last variable was calculated as a *z*-score to be used as an independent variable in the cluster analysis.

Cluster analysis

To determine the optimal number of clusters, a hierarchical cluster analysis was conducted to test the elbow method. The five PCs selected previously were used for this analysis. Ward's methods were applied to the five PCs to obtain coefficients of an agglomeration schedule. The coefficients' gap between 2,668 and 2,669 was much higher than the previous gaps. Thus, the optimal number of clusters was 5, which was obtained by subtracting 2,667 from 2,672.

A K-mean cluster analysis was performed using the five PC scores to categorize the whole BS. After testing two to six clusters, the five-cluster model was chosen (cluster 1: n = 502, 18.8%, cluster 2: n = 571, 21.4%, cluster 3 = 348, 13.0%, cluster 4: n = 593, 22.2%, cluster 5: n = 658, 24.6). The results for the two-cluster model (cluster 1: n = 1,345, 49.6%, cluster 2: n = 1,347, 50.4%, iteration stopped at 34), three-cluster model (cluster 1: n = 1,032, 38.6%, cluster 2: n = 574, 21.5%, cluster 3: n = 1,066, 39.9%, iteration stopped at 31), four-cluster model (cluster 1: n = 715, 26.8%, cluster 2: n = 427, 16.0%, cluster 3: n = 676, 25.3%, cluster 4: n = 854, 32.0%, iteration stopped at 46), five-cluster model (cluster 1: n = 502, 18.8%, cluster 2: n = 571, 21.4%, cluster 3: n = 348, 13.0%, cluster 4: n = 593, 22.2%, cluster 5: n = 658, 24.6%, iteration stopped at 31) and six-cluster model (cluster 1: n = 6, 0.2%, cluster 2: n = 586, 21.9%, cluster 3 = 501 18.8%, cluster 4: n = 364, 13.6%, cluster 5: n = 650, 24.3%, cluster 6:

Component	Eigenvalue	Rotated sums of squared loading % Of variance	Cumulative %
1	2.34	23.37	23.37
2	1.62	16.20	39.57
3	1.32	13.24	52.81
4	1.25	12.48	65.28
5	1.10	11.02	76.30

Note(s): There are 10 variations in the sample

Table 1. Total variance explained from pre-PC

Variable	Component 1	2	3	4	5
Back arc: Hip-Top hip	*0.803*	0.067	−0.011	−0.016	0.237
Buttocks angle	*0.799*	0.013	−0.04	0.017	−0.336
Width: Hip-Waist	*0.725*	0.213	0.129	−0.166	0.255
Front arc: Bust-Waist	0.053	*0.901*	0.041	−0.026	−0.094
Front depth: Bust-Waist	0.153	*0.846*	−0.065	−0.052	0.166
Back arc: Bust-Waist	−0.033	−0.02	*0.892*	−0.098	0.079
Back arc: Bust-Under bust	0.075	0.002	*0.881*	0.034	−0.051
Back length with bumps: Neck-waist	0.013	0.064	−0.008	*0.853*	−0.188
Back length without bumps: Neck-waist	−0.141	−0.173	−0.063	*0.765*	0.276
Front depth: Abdomen-Waist	0.127	0.052	0.02	0.024	*0.889*

Note(s): Values in italics are factor loadings above 0.50

Table 2. Rotated component matrix of PCA with 10 variables

$n = 565$, 21.1%, iteration stopped at 33) were calculated. In the six-cluster model, one cluster (cluster 1) was represented in less than 1% of the data overall. Therefore, the results verified that the five-cluster model was inappropriate for the whole BS categorization.

In the five-cluster model, the results of the one-way ANOVA showed the overall F was statistically significant at $p < 0.001$ for five PC variables that ranged from 241.04 to 518.72 (Table 3). A post hoc analysis showed that there were significant differences at the 0.05 level in the means of all of the five variables' possible pairwise comparisons, with the exception of PC4 (Back curvature) between Group 1 and Group 4, which did not differ, and the Z (Abdomen prominence) between Group 1 and Group 5, which did not differ. The means and standard deviations of the PCs' values were ranked a, b, c, d and e according to the magnitude of the mean value.

For the waist to hip silhouette and buttocks prominence (PC1), Group 1 (G1) had the widest hips from the front view and most prominent buttocks from the side view (0.84), followed by Group 5 (G5, 0.26), while Group 4 (G4) had the narrowest hips from the front view and the flattest buttocks from the side view (−0.66). For bust prominence from the side view (PC2), G5 had the most prominent bust (0.75), followed by G2 (0.39), while G2 had the least prominent bust from the side view (−1.06). With respect to the bust-to-waist back silhouette, G5 was the most sloped and tilted toward the back (0.75) followed by G2 (0.59), while G1 had the straightest and flattest back (−0.85). For the back curvature from neck to waist (PC4), G3 had the most outward upper back and most inward lower back (1.69), followed by G5 (−0.12), while G1 (−0.33) and G4 (−0.38) had the flattest back curvature from neck to waist. With respect to the abdomen prominence (Z) from the side view, G1 (0.61) and G5 (0.52) had the most prominent abdomen compared to the waist area, followed by G3 (0.05), while G4 had the least prominent abdomen (−0.90).

Body shape categorization (RQ1)

Table 4 shows the means and standard deviations of each BS group for the 10 variables. According to the one-way ANOVA, the overall Fs for all variables ranged from 32.42 to 2026.21 and differed significantly at $p < 0.001$. A post hoc analysis was also conducted to identify differences in each variable's means among the five BS groups.

As shown in Table 4, with respect to each BS's characteristics, G1 had relatively fewer differences in the front arc and depth, and back arc between the bust and waist levels compared to the other groups. G1 had the least back arc drop between the bust and under bust levels among the five groups. This results in a straight front and back upper body silhouette, which can be rectangle-shaped from both the front and side views. G1's lower body

Table 3. Means and standard deviations of PC for five body shape groups

PCs for cluster analysis	Body shape group G1 ($n = 502$)	G2 ($n = 571$)	G3 ($n = 348$)	G4 ($n = 593$)	G5 ($n = 658$)	F
PC1: Buttocks prominence	*0.84*^{a} (0.84)	−0.30^{d} (0.87)	−0.07^{c} (0.89)	−0.66^{e} (0.84)	0.26^{b} (0.87)	241.04***
PC2: Bust to waist silhouette	−0.21^{d} (0.84)	−1.06^{e} (0.72)	−0.06^{c} (0.86)	0.39^{b} (0.77)	*0.75*^{a} (0.67)	484.33***
PC3: Lower back silhouette	−0.85^{e} (0.75)	0.59^{b} (0.74)	−0.22^{c} (0.92)	−0.53^{d} (0.82)	*0.72*^{a} (0.68)	455.59***
PC4: Back curvature	−0.33^{c} (0.73)	−0.20^{b} (0.71)	*1.69*^{a} (0.98)	−0.38^{c} (0.71)	−0.12^{d} (0.70)	518.72***
Z: Abdomen prominence	*0.61*^{a} (0.88)	−0.24^{c} (0.75)	0.05^{b} (0.76)	−0.90^{d} (0.84)	0.52^{a} (0.84)	324.86***

Note(s): Means were ranked a, b, c, d and e ordered by magnitude. Standard deviations are in parentheses; $^{***}p < 0.001$

Variables for cluster analysis	Body shape group G1	G2	G3	G4	G5	F
PC1: Buttocks prominence						
Back arc: Hip – Top hip	1.20[a] (0.80)	0.34[d] (0.72)	0.51[c] (0.72)	0.15[e] (0.72)	0.89[b] (0.70)	99.85***
Buttocks angle	26.03[a] (4.70)	21.83[c] (4.84)	22.97[b] (4.60)	20.91[d] (4.68)	23.44[b] (4.68)	2026.21***
Width: Hip – Waist	4.02[a] (1.12)	2.79[b] (1.05)	2.80[b] (1.15)	2.67[b] (1.05)	3.91[a] (1.05)	243.90***
PC2: Bust to waist silhouette						
Front arc: Bust – Waist	4.47[c] (1.30)	3.40[d] (1.17)	4.59[c] (1.32)	5.28[b] (1.28)	5.83[a] (1.09)	508.83***
Front depth: Bust – Waist	−0.25[c] (1.00)	−1.40[e] (0.91)	−0.49[d] (0.99)	−0.10[b] (0.80)	0.41[a] (0.73)	265.74***
PC3: Lower back silhouette						
Back arc: Bust – Waist	0.09[c] (0.92)	1.61[a] (0.95)	0.41[b] (1.12)	0.34[b] (1.01)	1.41[a] (0.89)	329.21***
Back arc: Bust – Under bust	0.70[e] (0.86)	1.92[b] (0.78)	1.37[c] (0.94)	0.96[d] (0.86)	2.08[a] (0.75)	203.16***
PC4: Back curvature						
Back length with bumps: Neck-waist	0.25[c] (0.33)	0.28[c] (0.30)	1.03[a] (0.53)	0.27[c] (0.30)	0.33[b] (0.30)	42.30***
Back length without bumps: Neck-waist	17.18[c] (1.04)	17.49[b] (1.04)	18.92[a] (1.04)	17.12[c] (1.02)	17.23[c] (1.05)	221.30***
Z: Abdomen prominence						
Front depth: Abdomen – Waist	0.43[a] (0.34)	0.11[c] (0.29)	0.22[b] (0.29)	−0.15[d] (0.32)	0.40[a] (0.32)	32.42***

Note(s): Means are ranked a, b, c, d and e ordered by magnitude. Standard deviations are in parentheses; G1: Rectangle-curvy shape, G2: Parallelogram-moderately curvy shape, G3: Parallelogram-hip tilt shape, G4: Inverted trapezoid-moderately curvy shape, G5: Inverted trapezoid-hip tilt shape; ***$p < 0.001$

Table 4. Means and standard deviations of the five body shape groups in 10 body measurements

had the curviest shape in the front lower body silhouette with the widest hip compared to waist width. Further, G1 had the most prominent abdomen and buttocks in the lower body silhouette from the side view among the five groups.

Participants in G2 had a larger back arc at the bust level compared to that at the under bust and waist areas than did the other four groups. Because the bust from the side view does not appear to be more prominent, with a lower value of the front depth drop between the bust and waist areas than the waist and abdomen areas, the upper body silhouette overall from the side view looks like a parallelogram. For the lower body silhouette from the side view, G2 has a moderate buttocks and prominent abdomen, which results in a moderately curvy shape.

G3 has a similar upper body silhouette from the side view to that of G2, with a more prominent belly at the waist and abdomen levels than the bust level, while G3 has the curviest back (the most prominent upper back and the most inward curvature in the waist level). The lower body silhouette from the side view is referred to as the hip tilt shape because the inward curve in the lower back area is above the waist line, and is far from 180 degrees of the waist line compared to the floor that causes it to look different from G2.

G4's upper body silhouette has an inverted trapezoid shape from the side view, because the front and back depth at the bust level are larger than those at the waist level from the side view. Although G4 has the flattest buttocks and abdomen among the five groups, the lower body silhouette has a moderately curvy shape from the side view.

G5 has the most prominent bust and upper back at the bust level compared to the waist level from the side view, and has an inverted trapezoid shape, as G4 shows. G5's lower body from the front view has the greatest difference in width between the hip and waist levels, as in G1. G5 also has the most prominent abdomen in the lower body from the side view compared to that at the waist level among the five groups. Given that it has the second largest buttocks angle, the second largest difference in back arc between hip and top hip, and an inward curve in the waist area that is above the actual waist line, G5's lower body silhouette is referred to as the hip tilt shape, which may result from posture.

Each group's whole BS was classified based on the upper and lower body silhouette from the side view and lower body silhouette from both the front and side views (see Table 5). Before classifying the whole BS, the front and back upper body silhouettes from the side view were identified based on the silhouette lines in black and a 3D avatar created using CLO 5.1 software (see Figure 1). The silhouette lines were drawn based on points of the body measurements, such as width measures of bust, waist and hip areas from the front view and front X and back X on the bust, waist, hip, abdomen and buttocks from the side view. A total of 23 measurements required were extracted from the data to create a 3D virtual model in CLO, which included seven height measurements (total, bust, under bust, waist, top hip, hip, crotch), eight girth measurements (neck base, bust, under bust, waist, top hip, hip, thigh, upper arm), six length measurements (center front neck to waist, center back neck to waist, side neck to apex, apex to apex, total crotch length, across back shoulder) and a drop value (shoulder drop) and width value (back shoulder width). After overlapping the black silhouette lines with the 3D avatar, we elected to use the avatar to show the five categorized BSs because the avatars for the five BS groups offered a relatively accurate way to visualize each group's BS.

The population distribution among the BS groups identified were as follows: G1 (n = 502, 18.8%); G2 (n = 571, 21.4%); G3 (n = 348, 13.0%); G4 (n = 593, 22.2%) and G5 (n = 658, 24.6%). The demographic distribution of each BS group was analyzed based on the age ranges (Table 6). In the 18–25-year-old and the 26–35-year-old age range, the majority of the subjects was categorized in G5 (25.5%; 26.1%) and G4 (22.1%; 23.5%), while G3 (14.0%; 12.1%) had the smallest population. Most women in the 36–45-year old age range were classified in G5 (24.6%), followed by G2 (22.4%), while G3 (15.0%) included the fewest

Table 5. Whole body shape categories based on front upper body silhouette, front side view and back side view

Group	Side front upper body silhouette (Bust to waist)	Side back upper body silhouette (Neck to waist)	Front and side lower body silhouette (Waist to hip)	Whole body shape name
G1	Straight	Straight back	Curvy shape	Rectangle-curvy shape
G2	Upper abdomen prominent	Moderate curvature	Moderately curvy shape	Parallelogram-moderately curvy shape
G3	Upper abdomen prominent	Curvature	Hip tile shape	Parallelogram-hip tilt shape
G4	Bust prominent	Moderate curvature	Moderately curvy shape	Inverted trapezoid-moderately curvy shape
G5	Bust prominent	Curvature	Hip tilt shape	Inverted trapezoid-hip tilt shape

Note(s): G1: Rectangle-curvy shape, G2: Parallelogram-moderately curvy shape, G3: Parallelogram-hip tilt shape, G4: Inverted trapezoid-moderately curvy shape, G5: Inverted trapezoid-hip tilt shape

	G1	G2	G3	G4	G5	Total
Age						
18–25 years-old	131	156	105	165	191	748
	17.50%	20.90%	14.00%	22.10%	25.50%	100.00%
26–35 years-old	89	73	51	99	110	422
	21.10%	17.30%	12.10%	23.50%	26.10%	100.00%
36–45 years-old	141	184	123	171	202	821
	17.20%	22.40%	15.00%	20.80%	24.60%	100.00%
46–55 years-old	141	158	69	158	155	681
	20.70%	23.20%	10.10%	23.20%	22.80%	100.00%
Total	502	571	348	593	658	2,672
	18.80%	21.40%	13.00%	22.20%	24.60%	100.00%
Ethnicity						
Asian	12	48	9	26	26	121
	9.90%	39.70%	7.40%	21.50%	21.50%	100.00%
Mexican Hispanic	22	64	20	85	50	241
	9.10%	26.60%	8.30%	35.30%	20.70%	100.00%
African American (Non-Hispanic)	160	116	99	128	176	679
	23.60%	17.10%	14.60%	18.90%	25.90%	100.00%
Caucasian (Non-Hispanic)	245	231	167	242	303	1,188
	20.60%	19.40%	14.10%	20.40%	25.50%	100.00%
Hispanic (Non-Mexican)	16	58	27	68	48	217
	7.40%	26.70%	12.40%	31.30%	22.10%	100.00%
Other	47	54	26	44	55	226
	20.80%	23.90%	11.50%	19.50%	24.30%	100.00%
Total	502	571	348	593	658	2,672
	18.80%	21.40%	13.00%	22.20%	24.60%	100.00%
BMI						
Overweight (BMI of 25–29.9)	236	282	155	246	482	1401
	16.80%	20.10%	11.10%	17.60%	34.40%	100.00%
Obese (BMI ≥30)	266	289	193	347	176	1,271
	20.90%	22.70%	15.20%	27.30%	13.80%	100.00%
Total	502	571	348	593	658	2,672
	18.80%	21.40%	13.00%	22.20%	24.60%	100.00%

Note(s): G1: Rectangle-curvy shape, G2: Parallelogram-moderately curvy shape, G3: Parallelogram-hip tilt shape, G4: Inverted trapezoid-moderately curvy shape, G5: Inverted trapezoid-hip tilt shape

Table 6. Results of cross-tabulation of age and ethnic groups and whole body shape group

number of people. The largest groups in the 46–55 year-old age range were G2 and G4 (each with 23.2%), followed by G5 (22.8%), while G3 represented the fewest with 10.1%.

Table 6 also illustrates the five BS groups categorized according to ethnicity. Most Asians were categorized in G2 (39.7%), followed by G4 and G5 (each with 21.5%) and the fewest were categorized in G3 (7.4%). The majority of the Mexican Hispanics were categorized in G4 (35.3%) and G2 (26.6%). The non-Hispanic African American population was distributed primarily in either G5 (25.9%) or G1 (23.6%). Of the non-Hispanic Caucasians, most were in G5 (25.5%) and were classified fairly evenly into the other three groups (G1: 20.6%; G4: 20.4%; G2: 19.4%). Like the Mexican Hispanic population, the majority of the non-Mexican Hispanic population was categorized in G4 (31.3%) and G2 (26.7%). G5 (24.3%) was the largest BS group categorized for the Other ethnicity, while G3 (13.0%) was the smallest BS group categorized.

With respect to the BMI values, to divide the women into OW and OB groups, OW women were classified primarily as G5 (34.4%), followed by G2 (20.1%). G4 was the largest group

(27.3%) among the OB women, followed by G2 (22.7%) and G1 (20.9%), while G5 was the smallest group (13.8%).

Fit accuracy among five body shapes with ASTM sizing standards (RQ2)

Standard tables for the body measurements for curvy and straight plus sizes (ASTM D6960/D6960M-16) (ASTM International, 2016) and for curvy and straight misses sizes (ASTM D5585-11) (ASTM International, 2012) were used to compare with body measurements for each of the five BSs categorized (see Table 7).

The results showed that women in G1 and G4 would obtain a perfect fit in tops in the plus size curvy (G1:12.0%, G4:18.4%) and the misses straight (G1: 12.2%, G4: 16.4%) sizing systems. Less than 19% of women were able to find a perfect fit in all of the three body areas (i.e. bust, under bust and waist areas) while 42.6–60.4% of them had fit problems in at least one body area for tops in the plus curvy and the misses straight. Similarly, women in G2 and G3 would obtain a perfect fit in tops across the three sizing standards: Plus curvy (G2: 15.8%, G3: 15.2%), plus straight (G2: 14.2%, G3: 12.9%) and misses straight (G2: 15.9%, G3: 13.5%). About a half of women in G2 and G3 (47.7–59.2%) had fit problems at least one area of tops for plus curvy, plus straight and misses straight sizing. Interestingly, for women in G5, tops in the misses curvy (15.2%) and straight (11.9%) sizes offered the relatively more perfect fit; and fit problems at the same time compared to misses curvy (73.1%) and straight (78.9%) sizes.

For bottoms, the plus size curvy sizing system would offer a perfect fit for women in G1 (10.6%), while for women in G2 (11.9%), G3 (14.1%) and G4 (13.8%), a perfect fit would be obtained in the plus straight sizing system. For other sizing systems, less than 8% of women in G1-G4 had a perfect fit. Approximately a half of women in G1-G4 (42.8–58.8%) had fit problems in at least one area of bottoms in the four sizing systems. Finally, women in G5 would achieve a perfect fit in bottoms (6.4%) in the misses straight sizing system followed by bottoms (4.9%) in the plus curvy sizing system.

Conclusions and implications

Five whole BSs were categorized among OWOB females in the US: Rectangle-curvy shape; parallelogram-moderately curvy shape; parallelogram-hip tilt shape; inverted trapezoid-moderately curvy shape and inverted trapezoid-hip tilt shape. The OWOB females' BSs were identified primarily based on their side views, as five PCs explained the characteristics of their body from the side silhouette, although the first PC was related in part to the lower body from the front view. The results implied that OWOB females' whole BS differed significantly from the side views.

The whole BS was classified by combining the silhouette for the side upper and lower body. There were three different silhouettes for the side upper body: Rectangle; parallelogram and inverted trapezoid. Only one group was identified with the rectangle silhouette, where females have similarly prominent bust and upper abdomen areas and no curvature in the back upper body observed from the side. Females with more prominent upper abdomens compared to their bust areas and curvature in the upper back were classified as having a parallelogram shape in their side upper body silhouette. If females had a more prominent bust than their upper abdomen areas, with curvature in their upper back, their side upper body silhouette was categorized into the inverted trapezoid shape. There were two BS groups for each parallelogram and inverted trapezoid shape. However, the degree of curvature differed in each: For the parallelogram shape, those in G2 showed a more moderate curvature in their upper back than did those in G3, while for the inverted trapezoid shape, those in G4 had less curvature in their upper back than did those in G5.

With respect to the lower body silhouette, curvy, moderately curvy and hip-tilt shapes were identified among OWOB females. These results were consistent in part with those in

	Body shape group G1	G2	G3	G4	G5	χ^2
Tops in plus size: Curvy						
Perfect fit	60^{a}	90^{ab}	53^{ab}	109^{b}	21^{c}	
	12.0%	15.8%	15.2%	18.4%	3.2%	323.45^{***}
Fit problems	214^{a}	321^{b}	306^{b}	358^{b}	22^{c}	
	42.6%	56.2%	59.2%	60.4%	33.6%	
NA	228^{a}	160^{b}	89^{bc}	126^{c}	416^{b}	
	45.4%	28.0%	25.6%	21.2%	63.2%	
Bottoms in plus size: Curvy						
Perfect fit	53^{a}	30^{b}	21^{b}	15^{c}	32^{b}	
	10.6%	5.3%	6.0%	2.5%	4.9%	230.87^{***}
Fit problems	221^{a}	248^{a}	174^{a}	273^{a}	107^{b}	
	44.0%	43.4%	50.0%	46.0%	16.3%	
NA	228^{ab}	293^{bc}	153^{a}	305^{c}	519^{d}	
	45.4%	51.3%	44.0%	51.4%	78.9%	
Tops in plus size: Straight						
Perfect fit	47^{a}	81^{b}	45^{ab}	54^{a}	2^{c}	
	9.4%	14.2%	12.9%	9.1%	0.3%	
Fit problems	205^{a}	295^{b}	200^{bc}	374^{c}	161^{d}	409.22^{***}
	40.8%	51.7%	57.5%	53.1%	24.5%	
NA	250^{a}	195^{b}	103^{bc}	165^{c}	495^{d}	
	49.8%	34.2%	29.6%	27.8%	75.2%	
Bottoms in plus size: Straight						
Perfect fit	27^{a}	68^{b}	49^{b}	82^{b}	18^{c}	324.00^{***}
	5.4%	11.9%	14.1%	13.8%	2.7%	
Fit problems	246^{a}	275^{a}	189^{a}	291^{a}	134^{b}	
	49.0%	48.2%	54.3%	49.1%	20.4%	
NA	229^{a}	228^{ab}	110^{c}	220^{bc}	506^{d}	
	45.6%	39.9%	31.6%	37.1%	76.9%	
Tops in misses size: Curvy						
Perfect fit	14^{b}	27^{bc}	6^{a}	42^{c}	100^{d}	354.72^{***}
	2.8%	4.7%	1.7%	7.1%	15.2%	
Fit problems	294^{a}	273^{b}	151^{bc}	242^{c}	481^{d}	
	58.6%	47.8%	43.4%	40.8%	73.1%	
NA	194^{a}	271^{b}	191^{c}	309^{bc}	77^{d}	
	38.6%	47.5%	54.9%	52.1%	11.7%	
Bottoms in missy size: Curvy						
Perfect fit	22^{a}	3^{bc}	4^{cd}	1^{b}	20^{ad}	313.95^{***}
	4.4%	0.5%	1.1%	0.2%	3.0%	
Fit problems	246^{a}	281^{a}	149^{a}	279^{a}	544^{b}	
	49.0%	49.2%	42.8%	47.0%	82.7%	
NA	234^{a}	287^{ab}	195^{b}	313^{b}	94^{c}	
	46.6%	50.3%	56.0%	52.8%	14.3%	
Tops in misses size: Straight						
Perfect fit	61^{ab}	91^{bc}	47^{abc}	97^{c}	78^{a}	205.73^{***}
	12.2%	15.9%	13.5%	16.4%	11.9%	
Fit problems	298^{a}	290^{b}	166^{b}	272^{b}	519^{c}	
	59.4%	50.8%	47.7%	45.9%	78.9%	

(*continued*)

Table 7. Fit analysis for tops and bottoms based on plus size and misses size in ASTM sizing system among the five body shape groups

	Body shape group G1	G2	G3	G4	G5	χ^2
NA	143[a] 28.5%	190[ab] 33.3%	135[b] 38.8%	224[b] 37.8%	61[c] 9.3%	
Bottoms in misses size: Straight						
Perfect fit	37[a] 7.4%	10[b] 1.8%	18[ac] 5.2%	17[bc] 2.9%	42[a] 6.4%	228.18***
Fit problems	251[a] 50.0%	336[b] 58.8%	174[a] 50.0%	341[b] 57.5%	542[c] 82.4%	
NA	214[a] 42.6%	225[a] 37.4%	156[a] 44.8%	235[a] 39.6%	74[b] 11.2%	

Note(s): Frequencies are ranked a, b, c, d and e ordered by magnitude. NA: Not applicable; G1: Rectangle-curvy shape, G2: Parallelogram-moderately curvy shape, G3: Parallelogram-hip tilt shape, G4: Inverted trapezoid-moderately curvy shape, G5: Inverted trapezoid-hip tilt shape; ***p < 0.001

Table 7.

Song and Ashdown's (2011) study, in which females' lower bodies had curvy and hip-tilt shapes. Interestingly, no straight shape was identified, as their study on BS categorization focused on the general female population. A new lower BS category for the OWOB females was the moderately curvy shape. A moderately curvy and hip-tilt shape tended to relate to the side back upper body silhouette: If someone has curvature in her upper back, she is likely to have a hip-tilt shape in her lower body; if she has moderate curvature, her lower body silhouette will have a moderately curvy shape. These results were supported by a previous study on obesity and posture that found that obesity caused increased thoracic kyphosis and hyperlordosis (Fabris De Souza *et al.*, 2005). This difference may be because this study focused specifically on BMI groups of OWOB females.

This study is the first attempt to analyze perfect fit and fit problems for tops and bottoms by comparing the ASTM sizing charts with body measurements in newly identified BS groups. For G1, tops in straight missy size and in plus size for curvy, and bottoms in plus size for curvy were better than other sizing categories; for G2, tops in plus size for curvy, tops in misses and plus size for straight and bottoms in plus size for straight fit better than in other sizing systems; for G3 and G4, tops in plus size for curvy and in misses size for straight, and bottoms in plus size for straight fit better than in other sizing systems; for G5, tops in misses size for curvy and straight fit better than in other sizing systems. This sizing system provided the greatest number of perfect fits for bottoms in misses size for straight and fit problems. According to the results, less than four-fifths or more of OWOB female adults in the US would find it difficult to obtain a perfect fit for both tops and bottoms in the current ASTM sizing systems for both misses and plus sizes. This study has implications for apparel product developers and designers in the US, in that the sizing system for OWOB female adults needs to be revised according to the whole BS categories.

Identifying whole BSs among OWOB women in the US contributes significantly because it will help apparel companies that target the markets of larger women develop a new sizing system. Understanding larger women's BSs and related anthropometric characteristics will provide insights into the way the current ASTM sizing system needs to be updated. For example, OWOB women are likely to have fit problems in tops because of their looser fit in the bust areas if they choose tops based on their waist sizes. Further, they are likely to have fit problems in bottoms (i.e. looser fit in their hip areas) if they choose sizes based on their waist size. These results implied that apparel companies that target larger women in the US should consider modifying the waist sizes when they draft patterns that are larger than the current standardized sizing system. Improving the sizing system for larger female consumers will benefit them because they may experience less social discrimination and feel more included. Further, by reducing OWOB female consumers' perceived fit and size problems, apparel companies may achieve social responsibility and more economic benefits with fewer returns and exchanges (Faust and Carrier, 2010). In addition, if OWOB female consumers are better served, they will become loyal to a certain apparel brand that provides better fit and size, which in turn increases the company's revenues.

Furthermore, this study contributes to body-related literature by filling gaps in missing whole BS categories among OWOB females. This study has a methodological implication as well, in that the PCA and cluster analysis Song and Ashdown (2011) and Park and Park (2013) suggested were useful methods to categorize the whole BS from the front and side views simultaneously.

Limitations and future studies

This study used the SizeUSA data to categorize BSs in the OWOB female population in the US Future studies to confirm the BSs suggested and compare them using different datasets collected by different companies (e.g. SizeNA) may be conducted. Further research can also be conducted using the same methods to categorize BSs for OWOB men in the US. Lastly, although we included body measurements for both upper and lower bodies, but thigh girth was excluded due to the high correlation with other body measurements. In future studies, categorizing lower BSs among OWOB women may include thigh girth so that it can provide practical insights to improve the sizing system for bottoms.

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