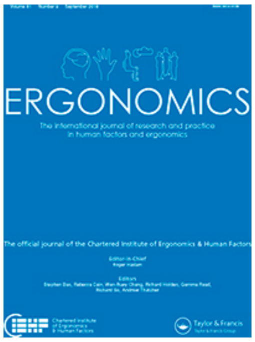

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The impact of age and body mass index on a bra sizing system formed by anthropometric measurements of Sichuan Chinese females

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The impact of age and body mass index on a bra sizing system formed by anthropometric measurements of Sichuan Chinese females

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Abstract: Existing bra sizing systems are based only on bust and underbust girths, which do not guarantee an accurate fit or comfort for consumers. This study presents a comprehensive investigation of the impact of age and body mass index (BMI) on bra sizing systems, and the distributions of band and cup sizes based on anthropometric measurement data. The first four principal components were extracted by principal component analysis, and the factor loadings of age and BMI were found to be significant determinants of bra size along with 12 other variables. Furthermore, chi-square analysis revealed that bra size allocations were significantly influenced by age and BMI. Thus, we propose that age and BMI should be considered as auxiliary criteria for the bra sizing system. Taken together, these findings will be of value to designers and bra manufacturers in developing well-fitting bras for their target consumers, and to consumers for selecting well-fitting bras with confidence.

Keywords: Bra sizing system; principal component analysis; age; body mass index

Practitioner Summary: This study contributes to an understanding of how bra sizing systems are affected by age and BMI. This understanding is valuable to bra designers, manufacturers, and retailers, as it will enable the adjustment of bra sizes for different target markets and in turn improve consumer confidence in selecting proper fitting and comfortable bras.

Abbreviations: BMI: Body mass index; KMO: Kaiser-Meyer-Olkin; PCA: Principal component analysis.

Introduction

Anthropometric measurement data is a significant influencing factor in the apparel industry (Widyanti *et al.*, 2017). Clothing size systems are based on anthropometric data and used to divide torsos into different categories (Jongsuk and Cynthia, 1996; Winks, 1997). This method provides an essential reference for fit and comfort (Vinué *et al.*, 2014). In 1935, Warner introduced alphabet bra cup sizes, which formed the basis of modern bra sizing systems (Pechter 1998; Yu et al. 2006). Current bra sizing systems generally consist of a numerical value and one or more letters, where the numerical value represents the band size, and the letter indicates the cup size (Tadisina *et al.*, 2016). Analogous bra sizing systems were adopted in different countries in metric or non-metric units of measure (Yu *et al.*, 2006). For instance, in the current Chinese industry standard for bra sizes, A75 or equivalently 75A both refer to a bra with an A cup and a band size of 75 (FZ/T 73012-2017). Where the band size range is dependent on underbust girth data, and the capital letter indicating cup size is categorically determined by the difference between the bust girth and the underbust girth (Ji, 2016; Zhang, 2017). Detailed grading rules are presented in Table 1 and Table 2. However, as the bra is one of the closest fitting body garments for females (Hardaker and Fozzard, 1997), depending only on the bust girth and underbust girth does not often offer consumers an accurate reference for assuring a comfortable fit. It has been reported that up to 69% of females suffer from discomfort due to wearing poorly fitting lingerie (White and Scurr, 2012). This discomfort may considerably affect women's health and quality of life and increase the need for breast reduction surgery.

There is an extensive body of literature focused on anthropometrics utilising three-dimensional (3D) human scanners to assist in the investigation of fit issues of bras. Lee, Hong and Kim (2004) explored an innovative digital computing approach by applying 3D human scanner to precisely measure female chest boundaries, making the valid point that 3D human scanner can be further exploited for the study of bra fit and appearance. Previous studies have also presented a cluster analysis and frequency distribution of the breast shapes and main chest shape characteristics of Western Chinese females to provide a technical basis for well-fitting bra design (Chen, Zhang and Tao 2008; Dong 2014). Liang, Zhang and Zhou (2007) divided Western Chinese female students into nine breast shape categories, investigating the differences between actual and ideal ratios of bust girth to the width and height of the chest. These comparisons were then used to define standard support bras. The range of female breast volumes and corresponding bra sizes has been measured, which demonstrated a variation between breast volumes and bra sizes (McGhee and Steele, 2011). In an attempt to select the optimal parameters, Liu, Wang and Istook (2017) offered a theoretical foundation for well-fitting made-to-measure bras intended for bra pattern makers.

Recent evidence suggests that age change and body mass index (BMI) alteration affect female breast features and preferences of bra design, colour, style and market (Clarke and Griffin, 2008; Risius *et* *al.*, 2012). Coltman, Steele, and McGhee (2017) specifically investigated the effects of aging on breast skin thickness and elasticity and the implications for breast support. It is further suggested that increasing female age would also increase variations of female physiological structure or hormones. In particular, skin and breast connective tissue loss could result in breast relaxation, sagging, and expansion (Boyd et al. 2009; Vandeweyer and Hertens 2002; Brown et al. 1999; Soares, Reid and James 2002; Haars et al. 2005). Coltman, Steele and McGhee (2018a) showed strong evidence that breast characteristics are greatly affected by age. Similarly, BMI also had a strong relationship with breast characteristics and breast volumes (Brown et al. 2012; Coltman, Steele and McGhee 2017, 2018b). Bra size plays an important role in the whole process of bra production (Porter *et al.*, 2004; Widyanti *et al.*, 2017), and is directly affected by breast characteristics. Nevertheless, it is still not clear how bra sizes are influenced by age and BMI. Therefore, this study aimed to comprehensively examine the effects of age and BMI on bra size using Principal Component Analysis (PCA) and chi-square analysis.

Methodology

Participants

Participants in this study were females from the Chinese Sichuan Province, who were randomly selected and stratified by age. None of the participants were pregnant or in the lactation period. The participants were divided into two age groups (age range: 20–29 years and age range: 40–49 years) according to ISO 7250-1 (2017), and three BMI categories (underweight: < 18.5 kg/m^2; normal weight: 18.5–24.9 kg/m^2; overweight: 25–29.9 kg/m^2) according to the World Health Organisation (2006). The first age group (range: 20–29 years) and the second age group (range: 40–49 years) were considered to be young females and mature females, respectively.

A 95% confidence level was applied in this study. The sample size was calculated by $n = \mu_\alpha^2 \times \sigma^2/_{\Delta^2}$. As a result, $n = 52$ was chosen as the minimum sample size. Assuming 10% of the measured data might be abnormal, the minimum sample size of each age group in this paper was determined to be $n = 60$. The final numbers of young and mature female participants were $n = 75$, and $n = 62$, respectively, meeting the statistical needs of this study.

Measurements

Manual measurements and non-contact 3D human scanner measurements were performed in this study to measure 20 essential variables of the bust area and upper torso. These variables were related to the determination of bra size according to the current Chinese Textile Industrial Standard for bra sizes (FZ/T 73012-2017). All variables are presented in Table 4. In order to ensure the accuracy of measurements, anthropometric landmarks were affixed to each participant prior to measurement. Martin anthropometric rulers were used for manual measurements; each participant, who wore minimal clothing and no shoes (ISO 7250-1 2017), was required to stand naturally on a horizontal measuring platform, to look straight ahead and to breath normally. A 3D human scanner (3D CaMega CF-1200) was applied to digitally measure the participants after manual measurements were obtained. During scanning, each participant stood with their feet approximately shoulder-width apart and their arms outstretched at an angle of approximately 15° to the torso (ISO 20685-1 2018). Subsequently, the scan data was imported into reverse engineering software Geomagic Qualify (3D Systems, Inc.) to acquire specific data. Manual measurements were used to obtain directly measurable values and check for errors in primary scanning data, such as bust girth and underbust girth. Body cross-sectional data such as thorax width, breast depth, and breast width were acquired through the 3D human scanner.

Statistical analysis

PCA was applied in order to identify the main influencing factors and fundamental requirements of the bra sizing system. Principal component extractions were performed on eigenvalues >1. Before PCA was performed, the Kaiser-Meyer-Olkin (KMO) test was used to examine the partial correlation between variables. Generally, when the result of the KMO test is greater than 0.7, the tested specimens are suitable for factor analysis. The component matrix was gathered to illustrate the influence of BMI and age on the bra sizing system. As the bra size system is comprised of band size and cup size, anthropometric measurement data were classified by grading data according to the Chinese Industrial Standard, as shown in Table 1 and Table 2. Chi-square analysis was performed to determine whether age or BMI significantly ($p<.05$) impact band size or cup size distribution. All statistics were computed by employing the Statistical Package for the Social Sciences (Version 25.0; IBM Corp.).

Table 1 Grading data of band size in the Chinese bra sizing system (FZ/T 73012-2017)

Table 2 Grading data of cup size in the Chinese bra sizing system (FZ/T 73012-2017)

Results

Principal component analysis

The KMO test result for this set of samples was 0.832, indicating that the tested specimen variables were suitable for PCA.

As shown in Table 3, it was clear that the extraction of four principal components, with a cumulative percentage of 81.506%, would be sufficient. Therefore, the first four principal components were sufficient to describe the bra size system, which also meets the actual requirements of production and sales.

Table 3 Total variance of measured variables

The principal component coefficient matrix is shown in Table 4 and summarizes the factor loadings of the first four extracted principal components (F_1, F_2, F_3 and F_4) for each variable. According to Table 4, the formulations of each principal component can be obtained as follows:

$$F_1 = 0.381x_1 + 0.897x_2 + 0.966x_3 + 0.552x_4 + 0.842x_5 + 0.431x_6 + 0.878x_7 + 0.589x_8 + 0.495x_9 + 0.601x_{10} + 0.219x_{11} + 0.906x_{12} + 0.273x_{13} + 0.880x_{14} + 0.466x_{15} + 0.926x_{16} + 0.895x_{17} + 0.852x_{18} + 0.816x_{19} - 0.216x_{20}$$

$$F_2 = 0.701x_1 - 0.114x_2 - 0.056x_3 - 0.402x_4 + 0.138x_5 - 0.140x_6 - 0.019x_7 + 0.516x_8 + 0.734x_9 + 0.270x_{10} + 0.114x_{11} - 0.034x_{12} - 0.650x_{13} - 0.404x_{14} + 0.776x_{15} - 0.056x_{16} - 0.017x_{17} - 0.023x_{18} - 0.510x_{19} + 0.053x_{20}$$

$$F_3 = 0.251x_1 - 0.313x_2 - 0.120x_3 + 0.544x_4 - 0.416x_5 + 0.636x_6 - 0.032x_7 + 0.198x_8 + 0.308x_9 + 0.245x_{10} + 0.140x_{11} - 0.083x_{12} + 0.659x_{13} - 0.015x_{14} + 0.252x_{15} - 0.120x_{16} - 0.032x_{17} - 0.416x_{18} + 0.158x_{19} + 0.240x_{20}$$

$$F_4 = -0.024x_1 + 0.144x_2 - 0.091x_3 - 0.174x_4 - 0.017x_5 + 0.043x_6 - 0.042x_7 - 0.100x_8 - 0.047x_9 + 0.052x_{10} + 0.902x_{11} - 0.080x_{12} - 0.046x_{13} + 0.110x_{14} - 0.043x_{15} - 0.091x_{16} - 0.061x_{17} + 0.157x_{18} + 0.081x_{19} + 0.237x_{20}$$

The first principal component F_1 (50.802%): The absolute value of coefficients of BMI, bust girth, bust girth minus underbust girth, bust girth minus waist girth, under breast line, distance between nipple and breast outside borderline, thorax width, thorax height, breast depth, and breast width were greater than those of the other variables. These ten variables occupied significant factor loadings in the first principal component.

The second principal component F_2 (15.302%): In this equation, the absolute value of coefficients of age, chest width, the distance between left and right under breast lines, and the distance between nipple and breast inside borderline were greater.

The third and fourth principal components F_3 (10.298%) and **F_4 (5.104%):** The coefficients of underbust girth, girth height, the distance between nipples, and the breast inside borderline, and the angle of right shoulder tilt were higher. These three variables the influence of other auxiliary data.

Table 4 Principal component matrix of measured variables

As displayed in Table 4, it is clear that the factor loadings of age, BMI, bust girth, bust girth minus underbust girth, under breast line, bust girth minus waist girth, chest width, the distance between nipple and breast outside borderline, the distance between left and right under breast line, thorax width, thorax height, breast depth, breast width, and the angle of right shoulder tilt were the greater, revealing that these variables are significant to the bra sizing system.

Effects of age and BMI on size distributions

The distributions of band sizes and cup sizes with respect to age and BMI categories are displayed in Figure 1.

Figure 1 The distribution of band size and cup size with respect to age and BMI categories

There were significant differences in age (*p*=.009) and BMI (*p*=.001) in the allocation of band sizes. Although each of the two age groups were counted in three band sizes (70, 75, and 80), the majority (85.33%) of young females were assigned to band sizes of 70 (33.33%) and 75 (52%), whereas most mature females were assigned to the band size of 75 (77.42%). During band size assignment with BMI classifications, underweight females were mainly distributed in the band size of 70 (78.9%), and a large percentage (91.1%) of normal weight females were distributed in band sizes of 70 (22.8%) and 75 (68.3%). Additionally, overweight females band sizes were predominantly distributed in a band size of 75 (82.4%), and there were no overweight females in the band size of 70.

Moreover, there were also significant differences between age (*p*=.000) and BMI (*p*=.000) classification on the allocation of cup size. As presented in Figure 1, young females were concentrated from an AA cup to a C cup. Conversely, the number of mature females allocated to larger cups was clearly greater than the number of young females in large cups. Similarly, females who had larger cups (D cup, G cup, E cup and F cup) had a greater tendency to be overweight, while underweight females were more likely to have smaller cup sizes (AA or A cups).

Discussion

This study offers valuable insight into the relationships between age, BMI and the bra sizing system, driven by measured anthropometric data from southwest Chinese females in two different age groups. Four principal components were extracted, and the factor loadings of age and BMI were found to be significant in the PCA (> 0.700). Thus, age and BMI were determined to affect distributions of band size and cup size significantly. The implications of this result is discussed in the following paragraphs.

Four principal components (F_1, F_2, F_3 and F_4) were extracted through PCA. The factor loadings of 14 variables—age, BMI, bust girth, bust girth minus underbust girth, under breast line, bust girth minus waist girth, chest width, the distance between nipple and breast outside borderline, the distance between left and right under breast lines, thorax width, thorax height, breast depth, breast width, and the angle of right shoulder tilt—were all greater than 0.700, which was the cut-off for significance (Zhang and Dong, 2013). Thus, these variables have significant impacts on the bra size. The two variables used in the traditional bra fitting method, bust girth and bust girth minus underbust girth (i.e. the difference between bust girth and underbust girth), are not sufficient as a reference standard for selecting a well-fit bra (Zheng, Yu and Fan 2007). As a unified standard for bra manufacturers, retailers and customers, the bra sizing system needs to be as concise as possible (White and Scurr, 2012) while ensuring accuracy. The factor loadings of two variables – bust girth (0.966) and bust girth minus underbust girth (0.878) – used in the conventional bra sizing system, were significant in F_1. This finding is in agreement with the current Chinese industry standard measurements for bra sizing (Ji 2016). The current bra sizing system comprised of numbers and letters (Tadisina *et al.*, 2016) is concise, however, without auxiliary criteria this traditional fitting method leads to an increased probability of consumers choosing inappropriately fitting bras. Previous reports have indicated that the majority of females wear incorrect bra sizes (Green et al. 2003; McGhee and Steele 2010; White and Scurr 2012) because of inaccurate traditional bra fitting methods. This is consistent with the PCA results described in this study where there are another 12 variables are similarly significant. Notably, the factor loading of BMI (0.897) was also significant in F_1. Moreover, age was a significant variable (0.701) with a greater absolute value of factor loading in F_2 than bust girth (-0.056) or bust girth minus underbust girth (0.138). Even though factor loadings of under breast line, distance between nipple and breast outside borderline, thorax width, thorax height, breast depth, and breast width were also significant (≥0.700) in the F_1, these parameters are difficult to measure without specialized devices. There were similar inaccessible measurable variables, for instance, chest width, the distance between left and right under breast lines, the distance between nipple and breast inside borderline and angle of right shoulder tilt. Conversely, age and BMI are easy for consumers, manufacturers and retailers to obtain without professional training or equipment. Regional female age and BMI statistics are easily obtained by bra manufacturers in industry standards from the local government for example, the detailed height and weight scales in the Chinese Standard Sizing Systems for Garments-Females (GB/T 1335.2-2008). The further chi-square analysis confirmed that both age and BMI considerably affect the distribution of the bra sizing system in terms of band sizes and cup sizes. Therefore, it is proposed that age and BMI are added to the traditional bra sizing system as additional criteria.

Age also has a significant effect on the distributive proportions band size (*p*=.009) and cup size (*p*=.000) distributive proportions. Age is known to affect women's physiology; for example, most mature females do not choose the bra sizes they wore when they were younger (Risius *et al.*, 2014). There is also literature (Green *et al.*, 2003; White and Scurr, 2012; Filipe *et al.*, 2015) investigating the influence of age on the applicability of traditional bra fitting approaches, and emphasising traditional fitting methods are not applicable for all ages. In this study, age was shown to have a significant effect on bra size determination, as shown in the second principal component (F_2), and this relationship was confirmed in the distribution of participant cup and band sizes. Although the females were distributed across all three band sizes (70, 75 and 80) in this study, mature females had a higher probability of wearing band sizes of 75 and 80, and a correspondingly lower likelihood of wearing a band size of 70, compared to young females. Furthermore, young females were more likely to wear bras with smaller cup sizes (AA cup, B cup and C cup). Conversely, mature females were more likely to wear bras with larger cup sizes (D cup, E cup, F cup and G cup). This finding is beneficial for bra manufacturers and sellers to appropriately adjust their production and sales according to age variances of their target customers. Furthermore, in accordance with the significant effect of aging, the age of subjects should be classified in further studies on bras and breasts.

There is a similar relationship between BMI and the bra sizing system, and allocations of bra band sizes and cup sizes are greatly influenced by BMI. In this paper, underweight females occupied the major portion of individuals wearing the smallest band size (70), whereas up to 80% of females wearing larger band sizes (80) were overweight. Interestingly, there were overweight females wearing small band sizes of 70 with cup sizes larger than E cup. According to the current Chinese industry standard for bra sizes (FZ/T 73012-2017), the quantity of data on bust girth minus underbust girth is greater for larger bra cup sizes. Thus, the existence of these subjects' data is reasonable. In addition, the largest cup size of underweight females was a C cup, while the smallest cup size of the overweight females was a D cup. Normal weight females were generally distributed in each range of band sizes and cup sizes. This result corresponds to the findings that clustering breast features are highly correlated with BMI (Brown et al. 2012; Coltman, Steele and McGhee 2017, 2018a). Overweight and obese females are more likely to have splayed, large to extra-large, and ptotic to very-ptotic breasts, while normal weight females are more likely to have small to medium and non-ptotic to mildly-ptotic breasts based on Coltman, Steele and McGhee's (2018a) study. Correspondingly, overweight and obese females have a two-to-three times greater breast volume than normal BMI females (Coltman, Steele and McGhee 2017). Thus, our current findings are in line with the results of previous studies regarding the significant influence of BMI on bra size.

This study, however, is subject to limitations. The research subjects were females aged 20–29 years and 40–49 years from Sichuan Province of China. Therefore, the above band size and cup size distributions only accurately reflect those from this region and within these two age groups. Compared with the participants of their study (Coltman, Steele and McGhee 2018a), there are no obese females in the present work, instead, women in Coltman, Steele and McGhee's (2018a) research did not contain underweight females. This is due to the fact that the measured subjects represent different regions and ethnicities. Brown et al. (2012) indicated that female breast sizes and torsos in different regions are dissimilar, thus, manufactures and sellers need to adjust the proportions of bra sizes for different localities. Further research is suggested to investigate the bra sizing systems of female subjects from different regions and countries. However, the findings that age and BMI influence appropriate bra sizing significantly can be easily be applied to a variety of regions and sizing systems without substantial barriers.

Conclusion

This study systematically explored the impact of age and BMI on the bra sizing system based on the anthropometric measurement of Sichuan Chinese females within two age groups. Through PCA, four principal components were extracted, and the component loadings of age and BMI were found to be significant. Both age and BMI have significant effects on the bra size and significantly affected the distributions of both band and cup sizes. The results further demonstrated that mature and greater BMI females are more likely to wear larger band and cup size bras, whereas younger and lower BMI females are more likely to wear smaller band size and cup size bras. Therefore, we propose the addition of age and BMI as auxiliary criteria for the bra sizing system to increase consumer confidence in the accuracy of bra fitting. These findings will be of interest to bra designers, manufacturers and retailers to adjust the assignments and production of bra sizes according to their target consumers.

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References

Boyd, N. *et al.* (2009) 'Breast-tissue composition and other risk factors for breast cancer in young women: a cross-sectional study', *The Lancet Oncology*, 10(6), pp. 569–580. doi: 10.1016/S1470-2045(09)70078-6.

Brown, N. *et al.* (2012) 'The relationship between breast size and anthropometric characteristics', *American Journal of Human Biology*, 24(2), pp. 158–164. doi: 10.1002/ajhb.22212.

Brown, T. P. L. H. *et al.* (1999) 'A method of assessing female breast morphometry and its clinical application', *British Journal of Plastic Surgery*, 52(5), pp. 355–359. doi: 10.1054/bjps.1999.3110.

Chen, H., Zhang, X. and Tao, N. (2008) 'Analysis of the morphological characteristics of the chest of young women based on three-dimensional anthropometry', *Journal of Xi'an Engineering University*, 22(2), pp. 75–78.

Clarke, L. and Griffin, M. (2008) 'Visible and invisible ageing: beauty work as a response to ageism', *Ageing and Society*, 28(5), pp. 653–674. doi: 10.1017/S0144686X07007003.

Coltman, C. E., Steele, J. R. and McGhee, D. E. (2017) 'Breast volume is affected by body mass index but not age', *Ergonomics*. Taylor & Francis, 60(11), pp. 1576–1585. doi: 10.1080/00140139.2017.1330968.

Coltman, C. E., Steele, J. R. and McGhee, D. E. (2018a) 'Effects of age and body mass index on breast characteristics: a cluster analysis', *Ergonomics*. Taylor & Francis, 61(9), pp. 1232–1245. doi: 10.1080/00140139.2018.1481229.

Coltman, C. E., Steele, J. R. and McGhee, D. E. (2018b) 'Which Bra Components Contribute to Incorrect Bra Fit in Women Across a Range of Breast Sizes?', *Clothing and Textiles Research Journal*, 36(2), pp. 78–90. doi: 10.1177/0887302X17743814.

Dong, C. (2014) *Research on 3D Virtual Model Based on Female Chest Features*. Donghua University.

Filipe, A. B. *et al.* (2015) 'The Fitting of Plus Size Bra for Middle Aged Women', *Procedia Manufacturing*, 3(Ahfe), pp. 6393–6399. doi: 10.1016/j.promfg.2015.07.968.

'FZ/T 73012-2017 Brassiere' (2017). Chinese Textile Industrial Standard.

'GB/T 1335.2-2008, Standard sizing systems for garments - Women'. China Textile Industry Association.

Green, A. R. *et al.* (2003) ‘An investigation of the suitability of bra fit in women referred for reduction mammaplasty’, *British Journal of Plastic Surgery*, 56(3), pp. 230–236. doi: 10.1016/S0007-1226(03)00122-X.

Haars, G. *et al.* (2005) ‘Measurements of Breast Density: No Ratio for a Ratio’, *Cancer Epidemiology Biomarkers & Prevention*, 14(11), pp. 2634 LP – 2640. doi: 10.1158/1055-9965.EPI-05-0824.

Hardaker, C. H. M. and Fozzard, G. J. W. (1997) ‘The bra design process - A study of professional practice’, *International Journal of Clothing Science and Technology*, 9(4–5), pp. 311–325. doi: 10.1108/09556229710175795.

‘ISO 20685-1, 3-D scanning methodologies for internationally compatible anthropometric databases – Part 1: Evaluatiob protocol for body dimensions extracted from 3-D body scans.’ (2018). The International Organization for Standardization.

‘ISO 7250-1, Basic human body measurements for technological design, Part 1: Body measurement definitions and landmarks’ (2017). The International Organization for Standardization.

Ji, A. (2016) ‘Interpretation of domestic bra products standards’, *SME management and technology*, 07, pp. 151–153.

Jongsuk, C.-Y. and Cynthia, R. J. (1996) ‘Key dimensions of women’s ready-to-wear apparel: Developing a consumer size-labeling system’, *Clothing and Textiles Research Journal*, 14(1), pp. 89–95. doi: 10.1177/0887302X9601400111.

Lee, H. Y., Hong, K. and Kim, E. A. (2004) ‘Measurement protocol of women’s nude breasts using a 3D scanning technique’, *Applied Ergonomics*, 35(4), pp. 353–359. doi: 10.1016/j.apergo.2004.03.004.

Liang, S., Zhang, X. and Zhou, J. (2007) ‘The basic form of breast in western female college students based on three-dimensional anthropometry’, *Journal of Textile Research*, 28(8), pp. 75–78. doi: 10.13475/j.fzxb.2007.08.020.

Liu, Y., Wang, J. and Istook, C. L. (2017) ‘Study of optimum parameters for Chinese female underwire bra size system by 3D virtual anthropometric measurement’, *Journal of the Textile Institute*. Taylor & Francis, 108(6), pp. 877–882. doi: 10.1080/00405000.2016.1195954.

McGhee, D. E. and Steele, J. R. (2010) ‘Optimising breast support in female patients through correct bra fit. A cross-sectional study’, *Journal of Science and Medicine in Sport*. Sports Medicine Australia, 13(6), pp. 568–572. doi: 10.1016/j.jsams.2010.03.003.

McGhee, D. E. and Steele, J. R. (2011) 'Breast volume and bra size', *International Journal of Clothing Science and Technology*, 23(5), pp. 351–360. doi: 10.1108/09556221111166284.

Pechter, E. A. (1998) 'A new method for determining bra size and predicting postaugmentation breast size', *Plastic and Reconstructive Surgery*, 102(4), pp. 1259–1265. doi: 10.1097/00006534-199809040-00056.

Porter, J. M. *et al.* (2004) '"Beyond Jack and Jill": Designing for individuals using HADRIAN', *International Journal of Industrial Ergonomics*, 33(3), pp. 249–264. doi: 10.1016/j.ergon.2003.08.002.

Risius, D. *et al.* (2012) 'Influential factors of bra purchasing in older women', *Journal of Fashion Marketing and Management*, 16(3), pp. 366–380. doi: 10.1108/13612021211246099.

Risius, D. *et al.* (2014) 'The influence of ageing on bra preferences and self-perception of breasts among mature women', *European Journal of Ageing*, 11(3), pp. 233–240. doi: 10.1007/s10433-014-0310-3.

Soares, D., Reid, M. and James, M. (2002) 'Age as a predictive factor of mammographic breast density in Jamaican women', *Clinical Radiology*, 57(6), pp. 472–476. doi: 10.1053/crad.2001.0873.

Tadisina, K. K. *et al.* (2016) 'Basics of Bra Sizing: Essentials for the Plastic Surgery Resident', *Plastic and Reconstructive Surgery*, 138(4), pp. 780-781. doi: 10.1097/PRS.0000000000002593.

Vandeweyer, E. and Hertens, D. (2002) 'Quantification of glands and fat in breast tissue: An experimental determination', *Annals of Anatomy*, 184(2), pp. 181–184. doi: 10.1016/S0940-9602(02)80016-4.

Vinué, G. *et al.* (2014) 'Looking for representative fit models for apparel sizing', *Decision Support Systems*. Elsevier B.V., 57(1), pp. 22–33. doi: 10.1016/j.dss.2013.07.007.

White, J. and Scurr, J. (2012) 'Evaluation of professional bra fitting criteria for bra selection and fitting in the UK', *Ergonomics*, 55(6), pp. 704–711. doi: 10.1080/00140139.2011.647096.

Widyanti, A. *et al.* (2017) 'Anthropometry of Indonesian Sundanese children and the development of clothing size system for Indonesian Sundanese children aged 6–10 year', *International Journal of Industrial Ergonomics*. Elsevier B.V, 61, pp. 37–46. doi: 10.1016/j.ergon.2017.05.008.

Winks, J. M. (1997) *Clothing sizes: International standardization*. Manchester: Textile Institute, pp. 1-67.

World Health Organisation (WHO). (2006) *BMI Classification.* Geneva: WHO.

Yu, W. *et al.* (2006) *Innovation and Technology of Women's Intimate Apparel*. Cambridge: Woodhead Publishing, pp. 26-58.

Zhang, W. and Dong, W. (2013) *Advanced Course of SPSS Statistical Analysis*. 2nd Edition. Beijing: Higher Education Press, pp. 215-234.

Zhang, Y. (2017) 'Selection of common bra standards', *Chemical fiber and textile technology*, 04, pp. 27–31.

Zheng, R., Yu, W. and Fan, J. (2007) 'Development of a new chinese bra sizing system based on breast anthropometric measurements', *International Journal of Industrial Ergonomics*, 37(8), pp. 697–705. doi: 10.1016/j.ergon.2007.05.008.

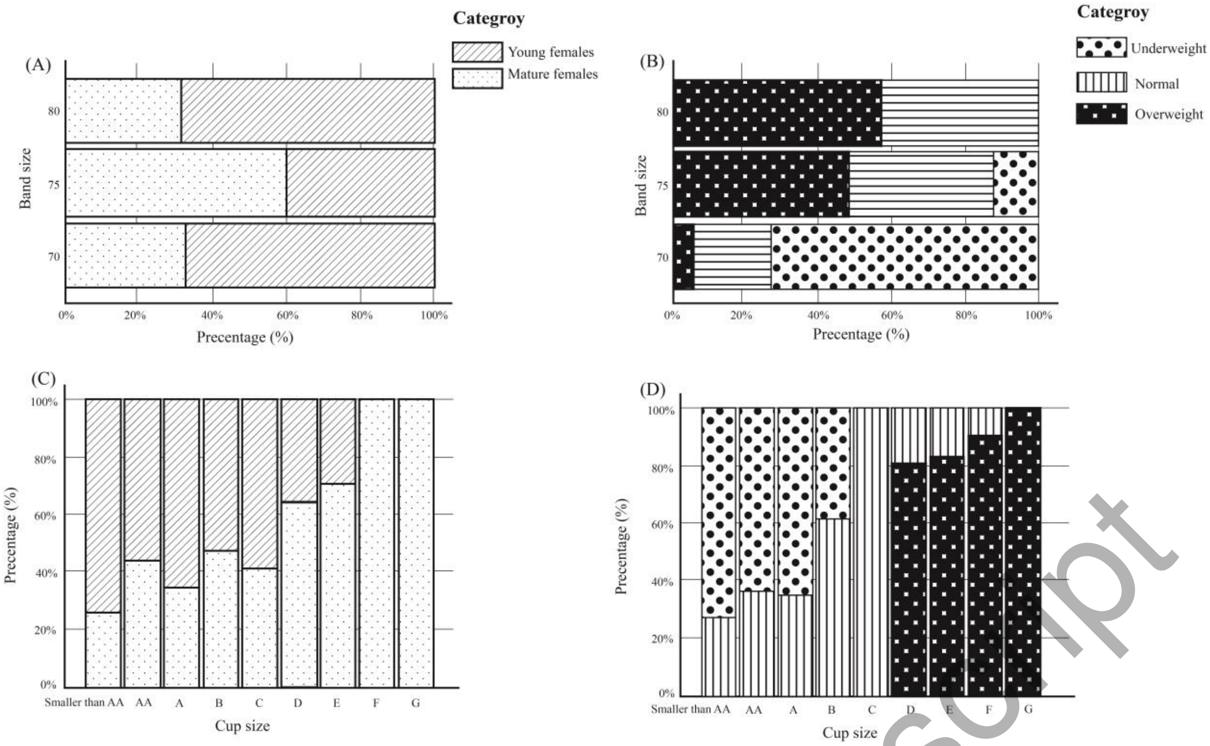
(A)
Categroy
Young females
Mature females
Band size
80
75
70
0%
20%
40%
60%
80%
100%
Precentage (%)
(B)
Categroy
Underweight
Normal
Overweight
Band size
80
75
70
Precentage (%)
(C)
Precentage (%)
Smaller than AA
AA
A
B
C
D
E
F
G
Cup size
(D)
Precentage (%)
Cup size

Table 1 Grading data of band size in the Chinese bra sizing system (FZ/T 73012-2017)

Band size	70	75	80
Under-bust girth /cm	67.5–72.4	72.5–77.4	77.5–82.4

Table 2 Grading data of cup size in the Chinese bra sizing system (FZ/T 73012-2017)

Cup size	AA	A	B	C	D	E	F	G
Bust girth minus under-bust girth /cm	6.25–8.74	8.75–11.24	11.25–13.74	13.75–16.24	16.25–18.74	18.75–21.24	21.25–23.74	23.75–26.25

Table 3 Total variance of measured variables

	Initial eigenvalues			Extracted sums of squared loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
F_1	10.160	50.802	50.802	10.160	50.802	50.802
F_2	3.060	15.302	66.104	3.060	15.302	66.104
F_3	2.060	10.298	76.402	2.060	10.298	76.402
F_4	1.021	5.104	81.506	1.021	5.104	81.506
F_5	.969	4.845	86.350			
F_6	.739	3.697	90.047			
F_7	.569	2.846	92.893			
F_8	.498	2.492	95.386			
F_9	.313	1.567	96.952			
F_{10}	.265	1.326	98.278			
F_{11}	.211	1.055	99.333			
F_{12}	.131	.657	99.990			
F_{13}	.002	.010	100.000			
F_{14}	4.865E-5	.000	100.000			
F_{15}	1.341E-5	6.707E-5	100.000			
F_{16}	9.863E-6	4.932E-5	100.000			
F_{17}	6.623E-6	3.311E-5	100.000			
F_{18}	6.038E-6	3.019E-5	100.000			

F_{19}	2.391E-6	1.195E-5	100.000
F_{20}	5.784E-7	2.892E-6	100.000

Extraction Method: Principal Component Analysis.

Table 4 Principal component matrix of measured variables

Measured variables	Elements	Principal components[a]			
		F_1	F_2	F_3	F_4
Age	x_1	.381	**.701**	.251	-.024
BMI	x_2	**.897**	-.114	-.313	.144
Bust girth	x_3	**.966**	-.056	-.120	-.091
Underbust girth	x_4	.552	-.402	.544	-.174
Bust girth minus underbust girth	x_5	**.842**	.138	-.416	-.017
Bust girth height	x_6	.431	-.140	.636	.043
Bust girth minus waist girth	x_7	**.878**	-.019	-.032	-.042
Distance between nipples	x_8	.589	.516	.198	-.100
Chest width	x_9	.495	**.734**	.308	-.047
Shoulder width	x_{10}	.601	.270	.245	.052
Angle of right shoulder tilt	x_{11}	.219	.114	.140	**.902**
Under breast line	x_{12}	**.906**	-.034	-.083	-.080
Distance between nipple and breast inside borderline	x_{13}	.273	-.650	.659	-.046
Distance between nipple and breast outside borderline	x_{14}	**.880**	-.404	-.015	.110
Distance between left and right under breast lines	x_{15}	.466	**.776**	.252	-.043
Thorax width	x_{16}	**.926**	-.056	-.120	-.091
Thorax height	x_{17}	**.895**	-.017	-.032	-.061
Breast depth	x_{18}	**.852**	-.023	-.416	.157
Breast width	x_{19}	**.816**	-.510	.158	.081
Difference between left and right height of bust girth	x_{20}	-.216	.053	.240	.237

Extraction Method: Principal Component Analysis.

[a] First four components extracted.

Values in bold are ≥0.700.