Breast Anthropometry Measurements of Chinese Adolescent Girls for Sports Bra Design

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Abstract

Breast measurement is one of the most challenging aspects of anthropometric studies. Considering the specific breast shapes and needs of adolescent girls, the purpose of this study is to investigate breast anthropometry measurements and perceptions of bra design in adolescent girls. 23 adolescent girls aged 10 to 14 were invited to participate in the survey to understand their knowledge level of bra-related issues, and 7 adolescent girls with bra sizes of 30AA to 32A were invited for wear trials. Five bra conditions were introduced, and 3D scanning, and questionnaires were conducted to obtain seven breast measurements and understand their preferences for bra design. Results showed that only 8.70% of respondents had experienced bra fitting, and less than half knew how to determine bra size, highlighting an education gap on this important topic. The upper bust measurement was significantly correlated with the level of "coolness" (r = -0.395 and p = 0.038), and the under bust measurement was correlated with the level of "comfort" (r = -0.441 and p = 0.019). This implies that fabrics with higher air permeability and water vapour transmission rate are required in the upper breast region, and a highly stretchable underband is preferred to comfortably fit the rapidly growing body during adolescence. These results highlight the need to design sports bras specifically for adolescents and provide bra designers with important information about the bra design features and dimensions required for optimal wear comfort during physical activities.

Keywords: Breast Shape; body Measurement; 3D Scan; Subjective Questionnaire; Early Bra Education

1. Introduction

As awareness of health increases, there is a significant growing demand for sports bras suitable for women to wear during exercise. Sports bras are designed to provide support and comfort during physical activity. However, problems with poorly fitting bras and inadequate designs are often reported, leading to pain and friction injuries. Precise breast measurements can help select the correct bra size, but the varying shapes of breasts indicate the need for more diverse and inclusive designs [1]. This is especially crucial for adolescent girls, whose bodies are still growing and developing.

Breast measurement is one of the most challenging aspects in anthropometric studies due to the deformability of breast tissues and the variety of breast profiles [2]. This complexity is heightened when considering the specific needs of adolescent girls. To the best of our knowledge, there has been no comprehensive research into the body and breast shapes of adolescent girls about sports bras. Further research is strongly recommended to fill this knowledge gap.

Adolescence is a period of rapid physical, cognitive and psychosocial growth. Research has shown that active adolescents have a better perception of life and improved physical, mental, social, and emotional health [3]. However, 85% of adolescent girls do not meet the recommended level of physical activity, often due to breast issues [4]. In the United Kingdom, 76% of girls reported at least one breast-related concern during exercise, including breast bounce [5]. Despite the importance of proper breast support, education is rarely provided by public health services or schools. Recent studies have emphasised the need for breast education for adolescent girls, ideally starting before the age of 18 [6]. However, there has been no research on this topic among Hong Kong's adolescent girls on breast education. Therefore, a survey is needed to investigate bra-related issues among Hong Kong's adolescent girls.

Adolescents have unique needs for bra fitting and breast support as their breasts grow, and it's common for them to experience tenderness or soreness. They are often self-conscious about their bodies, particularly about excessive

breast movement during exercise. Traditional exercise clothing for adolescents, such as tank tops, often lack adequate breast support, and their sizes are typically vague. This study aims to investigate the breast anthropometry measurements and perceptions of bra design in adolescent girls, providing valuable information for bra designers to create designs for optimal fit, comfort, and protection during physical activities.

2. Method

This study employed qualitative and quantitative research methods, divided into two stages. The first stage, using a questionnaire, aimed to investigate the needs of adolescent girls for sports bras and the potential challenges they might encounter when choosing and fitting sports bras. Stage 2, conducted through a wear trial, aimed to examine the breast anthropometry measurements and perceptions of adolescent girls regarding the design of sports bras.

2.1 Participants

In this study, bra-related issues were investigated with a total of 23 Chinese adolescent girls aged 10-14. Key breast measurements were identified to design sports bras with 7 adolescent girls with a bra size of 30AA to 32A, who are members of school sports teams. Participants have a regular exercise routine and a higher frequency of sports bra usage. The study received approval from the Human Subjects Ethics Sub-committee of the University (HSEARS20230531003). All participants and their guardians provided written informed consent before participating in the study. The participants' demographic information, including age, height, weight, body mass index (BMI), and bust and full bust measurements, is provided in Table 1.

Table 1. Demographics of participants

	Stage 1	Stage 2
Number of subjects	23	7
Age (years)	12.14 (± 1.14)	12.29 (± 1.39)
Height (cm)	153.16 (± 7.52)	152.93 (± 5.61)
Weight (kg)	43.15 (± 6.68)	42.77 (± 5.37)
BMI (kg/m^2)	18.36 (± 2.03)	18.41 (± 1.37)
Under bust (cm)	67.55 (± 4.39)	64.71 (± 3.93)
Full bust (cm)	75.13 (± 6.48)	71.14 (± 4.31)

2.2 Data Collection

In stage 1, a survey was distributed to 23 adolescents to understand their bra selection habits, attitudes and knowledge level regarding bra selection. During the wear trial in stage 2, a standard 2-minute Zumba dance exercise was introduced to allow participants to experience the feel of the bra during physical activity. Following the exercise, a questionnaire was conducted using a 10-point Likert scale, where "1" denotes the worst performance and "10" denotes the best performance. The respondents evaluated Eight criteria after exercise, including design satisfaction, ease of wear, pain, support, comfort, fit, smooth hand feel, and coolness.

In this study, five bra conditions, including a camisole top made of cotton (condition a), a soft bra (condition b), a pullover racer back seamless knitted sports bra made of polyamide and elastane (condition c), an adjustable straight back cut and sewn sports bra made of polyester, polyamide and elastane (condition d), and an adjustable racer back cut and sewn sports bra made of polyester and polyurethane (condition e) were evaluated (Fig.1). The soft bra (condition b) with minimal coverage was used in the experiment to simulate braless condition. The breast anthropometric measurements of the participants were captured using a handheld full-color three-dimensional (3D) scanner with a high 3D resolution of up to 0.2 mm and accuracy of up to 0.1 mm (Artec Eva, Artec Europe). This scanner's reliability, accuracy and reproducibility have been validated in previous studies [7]. The scanned images were processed by using Artec Studio 13 Professional software.

To determine the shape of the breasts, ten markers were used to assist in measuring seven breast anthropometry aspects, including the circumferences of full bust, under bust, and upper bust, distances between bust points (BP distance), bust prominence, degree of the curvature of the back, and breast ptosis. The measurement method is

illustrated and listed in Fig.2 and Table 2. To scan the image without hiding any landmarks, the subjects were asked to stand straight, facing forward, with arms outstretched and elbows bent.

The circumferences of full bust, under bust, and upper bust are typically used as indicators to determine bra size. The back's curvature is determined by an angle, with a smaller angle suggesting a more hunched back. Breast ptosis is categorised into four grades [8]. The grading scale is determined by the vertical distance between the nipple and the inframammary fold (IMF), with the degree of breast ptosis classified as follows: Grade 0 (no ptosis), with a vertical distance from the nipple to the IMF greater than 0 cm; Grade 1 (minor ptosis), with a vertical distance from 0 to -1 cm; Grade 2 (moderate ptosis), with vertical distance from -1 to -3 cm; and Grade 3 (advanced ptosis), with vertical distance less than -3 cm.

Compared to traditional measurement methods using a soft tape, 3D scanning provides accurate and repeatable representations of breast shape. 3D scanning can obtain linear measurements, including point-to-point distance, circumferences, and angles [9]. In this study, the scanning was carried out by experienced personnel, and all measurements were processed and taken by the same trained personnel using reverse engineering software (Geomagic Design X, Artec Europe) to ensure accuracy and consistency. XYZ coordinates were aligned to obtain the measurements accurately. Each measurement was taken twice, and the average will be used for analysis.

2.3 Data Analysis

One-way ANOVA was used to evaluate the statistical significance of the differences in the measurement outcomes between different bra conditions. The level of significance was set at 0.05. Pearson's correlation was also applied to investigate the potential relationship between breast measurements and subjective feelings, providing bra design recommendations.
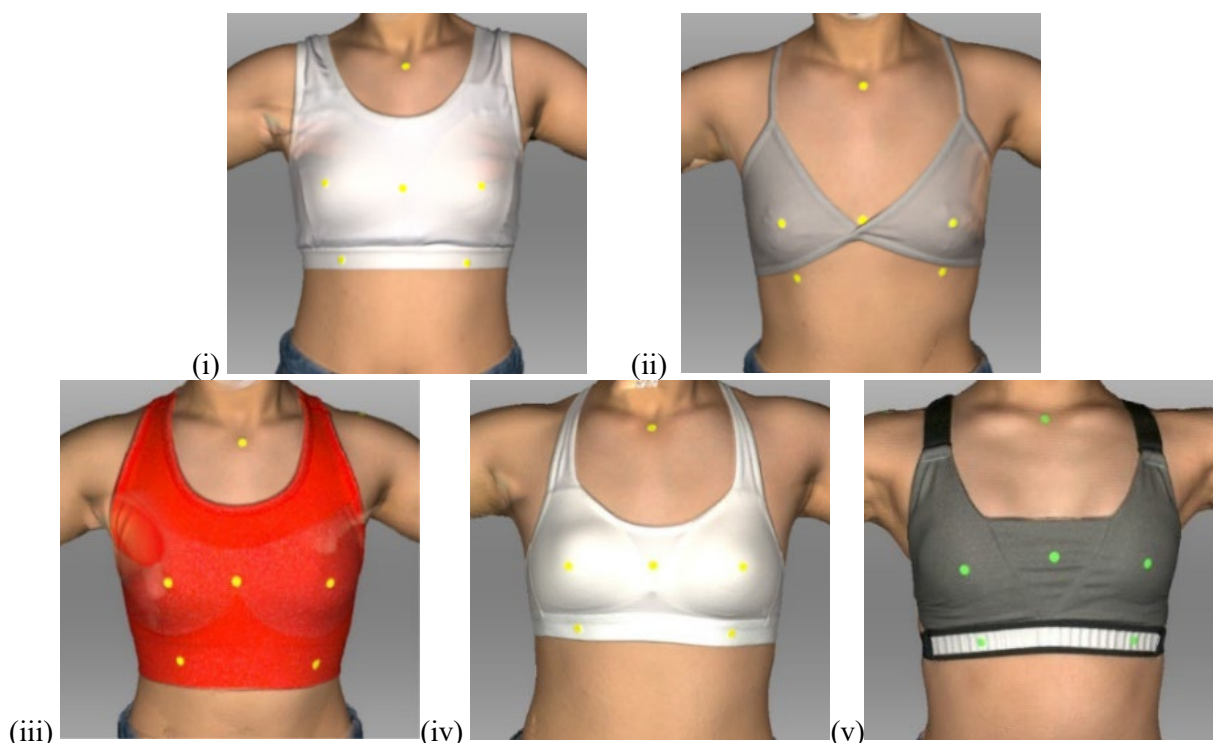

Fig.1 3D scanned image with landmarks of (i) a camisole top, (ii) a soft bra, (iii) a pullover racer back seamless knitted sports bra, (iv) an adjustable straight back cut and sewn sports bra, and (v) an adjustable racer back cut and sewn sports bra
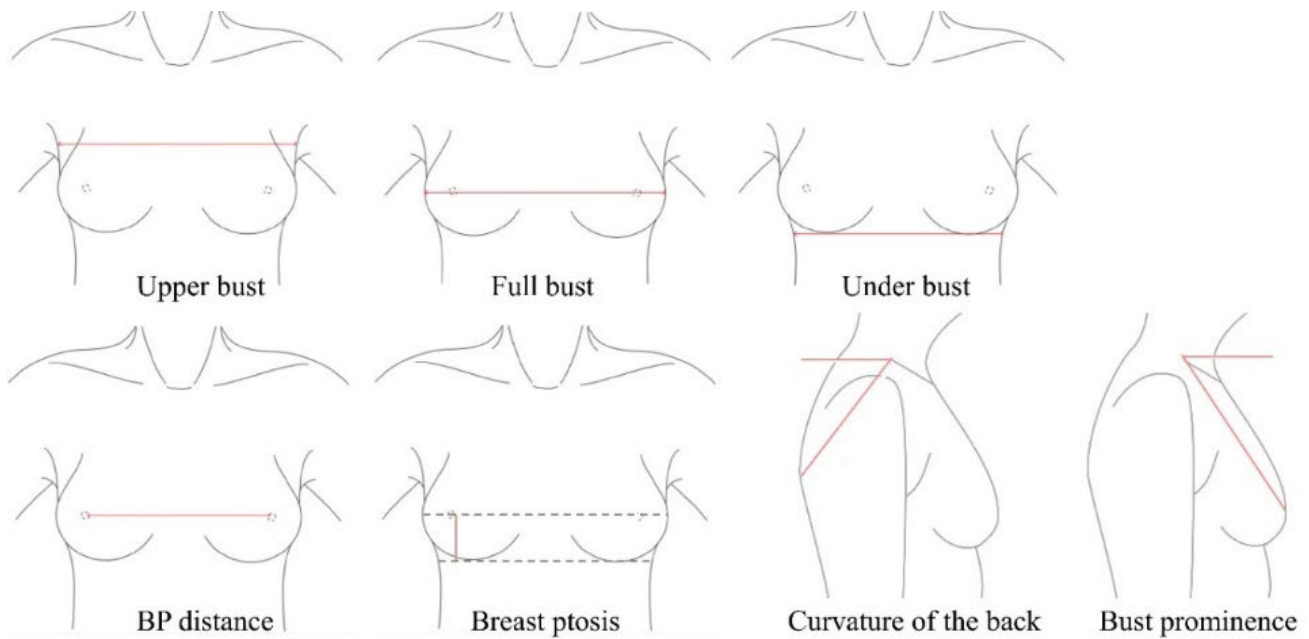
Fig.2 Illustration of the anthropometric measurements

Table 2. Anthropometric measurements

Measurement	Definition	Reference point
Upper bust (cm)	Circumference of chest around armpits	Point on armpits
Full bust (cm)	Circumference of the chest over the fullest part of the breasts	Point on nipples
Underbust (cm)	Circumference of the chest directly underneath the breasts	The point on the rib cage
BP distance (cm)	From left to right nipple	Point on nipples
The curvature of the back (°)	The angle between the horizontal plane and the connecting line of the point at the side of the neck and scapula prominence	The point at the side of the neck and scapula prominence
Bust prominence (°)	The angle between the horizontal plane and the connecting line between the point at the side of the neck and the nipple	The point at the side of the neck and nipples
Breast ptosis (cm)	Vertical distance between nipple to IMF	Point on nipple and IMF

3. Results

3.1 Bra Selection Habits and Attitudes

In stage 1 of the study, 23 adolescent girls were surveyed about their bra selection habits and attitudes. The results revealed that 82.61% of the respondents had bras chosen by their parents, indicating a potential lack of knowledge in bra selection. Only 8.70% had experienced bra fitting, suggesting a lack of awareness or access to professional bra fitting services. Amongst the participants, 34.78% have learnt how to determine their bra size, highlighting a gap in education on this essential topic. Results also revealed that 34.78% of the respondents were confused about the topic of breasts and bras. Around 43.48% of them felt embarrassed about the related discussions. Additionally, 43.48% of the participants reported experiencing discomfort when wearing a bra, emphasising the urgent need for more comfortable and well-fitted bra designs for adolescent girls.

3.2 Measurements and Subjective Rating

A survey was distributed for completion, asking participants to rate eight criteria on a scale of 0 to 10 after exercise. The participants' perceptions of bra design features were then analysed. Descriptive results and one-way ANOVA analysis are presented in Table 3. The results of Pearson's correlation show that the level of "easy to wear" is significantly associated with full bust measurement ($r = -0.403$ and $p = 0.034$), under bust measurement ($r = -0.432$ and $p = 0.022$), upper bust measurement ($r = -0.434$ and $p = 0.021$), BP distance ($r = -0.38$ and $p = 0.046$) and curvature of the back ($r = -0.525$ and $p = 0.004$). The upper bust measurement is also significantly associated with the level of "coolness" ($r = -0.395$ and $p = 0.038$). Finally, yet importantly, the under bust measurement is associated with the level of "comfort" ($r = -0.441$ and $p = 0.019$).

Table 3. Descriptive results and One-way ANOVA analysis of subjective analysis

	Condition	Mean	SD	P		Condition	Mean	SD	P
Satisfaction	a	7.071	1.694	0.884	Support	a	6.643	3.250	0.061
	c	6.857	3.436			c	7.714	2.690	
	d	7.571	1.718			d	8.571	1.134	
	e	6.571	3.155			e	9.500	0.500	
Easy to wear	a	8.286	1.976	0.191	Comfort	a	7.071	2.009	0.786
	c	7.143	1.773			c	7.071	2.168	
	d	6.286	1.799			d	5.929	3.194	
	e	5.143	3.532			e	6.000	3.215	
Pain	a	0.286	0.756	0.723	Fit	a	7.143	3.132	0.096
	c	1.000	1.915			c	7.714	2.690	
	d	0.571	1.134			d	7.000	3.416	
	e	0.857	1.464			e	9.500	0.764	
Smoothness	a	7.857	3.761	0.633	Coolness	a	6.571	3.599	0.662
	c	7.000	3.651			c	6.857	2.116	
	d	5.143	3.976			d	6.500	3.069	
	e	7.286	2.928			e	8.000	2.082	

3.3 Measurements and Demographic Data

Pearson's correlation showed that age is significantly related to height ($r = 0.928$ and $p = 0.003$) and weight ($r = 0.816$ and $p = 0.025$). In stage 2, seven breast measurements were performed under five different bra conditions, with a soft bra simulating the braless condition. Table 4 presents the results of one-way ANOVA, with the calculated mean value and standard deviation for measurements across different sports bra conditions. After analysing the measurements of condition B, Pearson's correlation results indicated that BMI is significantly associated with upper bust ($r = 0.791$ and $p = 0.034$), full bust ($r = 0.811$ and $p = 0.027$), and breast ptosis ($r = 0.845$ and $p = 0.017$). The mean value of the degree of breast ptosis among adolescent girls in a soft bra is 5.13°. All subjects were categorised for breast ptosis and considered Grade 0, indicating no ptosis. BP distance is used as a reference to create a more aesthetically pleasing breast profile. The result of this study showed that BP distance is significantly associated with age ($r = 0.919$ and $p = 0.003$), weight ($r = 0.937$ and $p = 0.002$), and height ($r = 0.762$ and $p = 0.047$). Results also indicate that wearing different sports bras can significantly affect the BP distance and the degree of breast ptosis, with p-values of 0.043 and 0.006, respectively. The BP distance refers to the distance between the bust points, while breast ptosis refers to the degree of sagging or drooping of the breasts.

Table 4. Descriptive results and One-way ANOVA analysis of breast measurements

	Condition	Mean	SD	P		Condition	Mean	SD	P
Full Bust (cm)	a	71.64	5.137	0.956	Breast ptosis (cm)	a	6.88	1.773	0.006**
	b	71.07	4.773			b	5.13	1.610	
	c	70.36	4.607			c	8.26	1.190	
	d	72.43	5.086			d	6.37	0.524	
	e	71.00	4.010			e	7.19	0.602	
Under Bust (cm)	a	64.93	4.004	0.836	Bust prominence (°)	a	62.51	5.970	0.453
	b	64.86	3.945			b	63.32	7.834	
	c	62.86	3.351			c	62.08	3.943	
	d	64.50	3.304			d	58.21	4.790	
	e	64.00	4.975			e	59.72	5.005	
Upper Bust (cm)	a	72.19	4.924	0.991	The curvature of the back (°)	a	38.20	9.649	0.756
	b	71.64	3.987			b	39.89	7.032	
	c	71.57	4.334			c	41.86	2.757	
	d	71.93	5.004			d	43.15	8.055	
	e	72.71	4.716			e	43.63	7.040	
BP Distance (cm)	a	14.86	1.319	0.043*					
	b	15.51	1.533						
	c	15.46	1.086						
	d	14.83	1.718						
	e	16.46	0.598						

Note. * p < .05, ** p < .01, *** p < .001

4. Discussion

4.1 Difficulties in Sports Bras Selection

Adolescent girls are at a stage where they are beginning to wear bras. However, their need for a comfortable bra, which is of great importance, is often overlooked due to limited research on bra designs. This study aims to provide insights into sports bra design, particularly catering to the needs of Chinese adolescent girls. Results showed that participants were confused about the topic of breasts and bras, possibly due to a lack of relevant educational knowledge, such as bra selection and bra fit. This underscores the need for more open dialogue and education about these natural bodily changes and the importance of proper bra fit and selection, which aligned with a survey of 2,089 schoolgirls in the United Kingdom [5], as about half of the participants felt embarrassed on the related discussion. Co-creation workshops may be adopted in schools to enhance the acceptance and awareness of the topic [10]. Positive results in terms of psychological value and satisfaction can be expected.

4.2 Impact of Measurements on Subjective Perceptions of Bra Designs

The results of Pearson's correlation show that the level of "easy to wear" is significantly negatively correlated with the measurements of full bust, under bust, upper bust, and BP distance, which means as the measurement increases, the ease of wearing a bra decreases. This suggests that individuals with larger breasts and a more pronounced curvature of the back may pose more challenges when it comes to putting on a bra. These findings highlight the importance of designing bras with more adjustable features or alternative fastening methods to accommodate different body shapes and sizes.

The upper bust measurement is significantly negatively correlated with the level of "coolness", suggesting that

individuals with larger upper bust measurements feel less cool. This could be due to the increased surface area and insulation larger breasts provide. This result also implies that thermal sensation is more noticeable in the upper breast region, requiring fabric and design with higher air permeability and water vapour transmission rate.

Moreover, the under bust measurement is significantly negatively correlated with the " comfort " level. Females often complain about tight underbands restricting chest movement, particularly affecting the lungs, which move up and down during breathing, and the stomach, which expands during digestion. A well-fitting underband with suitable width and smoothness for minimal bra displacement is crucial for a comfortable bra. Studies have shown that bra band size increases with age [11]. Given the rapid growth of adolescents during adolescence, a highly stretchable underband with superior recovery and softness is preferred.

4.3 Relationship between Body Measurements and Demographic Data

Pearson's correlation showed that age has a significantly positive relationship with height and weight. As individuals age, they tend to become taller and heavier. Previous studies provided similar results, indicating a significant relationship between age, height, weight, and BMI [12]. A study comparing the demographic data of 28 adolescent girls aged between 19 and 33 and 26 older females aged between 50 and 70 found significant differences in height, weight, and BMI between the two age groups [12]. This demonstrates that body shape differs significantly with ageing. It is also suggested that the increase in BMI value is highly correlated with other parameters, including bust circumferences, BP distance, breast ptosis, and bust prominence. Significant differences were observed between younger and older females regarding bust circumferences and breast ptosis [12]. In this study, adolescents have a mean BMI value below 18.5 (Table 1), which is classified as underweight in Asian adults [13]. Their breast shapes will differ significantly from those of adults. Further investigation should be conducted to understand the detailed body geometry of adolescents, and ageing should be considered as a factor for bra design, especially for sizing and pattern making.

Moreover, BMI significantly correlates with upper bust, full bust, and breast ptosis. This suggests that BMI conventionally determines breast volume and shape, directly affecting the cup size. This finding aligns with previous literature indicating that breast ptosis is associated with a higher BMI value [14]. Our study found that no subjects had ptosis. Ptosis is positively correlated with age. The breasts will sag when the skin and Cooper's ligament lose elasticity [12]. Adolescents who are in the breast growth period do not have this problem. The bra design does not require special features to prevent sagging. In addition, the BP distance of the adolescent girls is less than 20 cm, which is closer than the ideal distance [15]. Since BP distance is significantly positively correlated with age, weight, and height, this result may be due to their younger age, lower weight, and height. The gathering effect appears to be less important as a design feature. Changes in breast shape can significantly influence bra designs, and given the different shapes of breasts, adolescent bras should be specifically designed.

4.4 Breast Measurements and Features of Sports Bras

The result suggests that the breasts are lifted when wearing sports bras, particularly with a pullover racer back seamless knitted sports bra, which could potentially reduce the degree of breast ptosis. This effect is likely due to the stretchability of the knitted structure, which conforms closely to the body and provides effective lifting by fitting into the area beneath the breasts. Following the biomechanics of breast support [16], sports bras can provide the necessary support to maintain the shape and position of the breasts, which can help prevent discomfort and potential damage to the breast tissue. Furthermore, the study found that the BP distance appears to spread apart when wearing condition e, which refers to an adjustable racer back cut and sewn sports bra. This may indicate that this particular design of sports bras spreads the breasts widely, adversely affecting aesthetic breast contours.

5. Conclusion

This study conducted surveys and wear trials to understand the bra design needs of adolescent girls in Hong Kong. Results show gaps in breast education. The results show a significant correlation between the breast measurements and subjective perceptions of the bras, highlighting the importance of considering adolescent girls' unique breast anthropometric measurements in sports bra design. Sports bras need to be specially designed for adolescents, such as adding highly stretchable underband or knitted structure to cope with the rapid growth of adolescence and using

fabrics with higher breathability and water vapor permeability in the upper breast region. The enhanced design can significantly increase adolescent girls' comfort in physical activities, thereby promoting their participation in physical activity. This study provides valuable insights into breast anthropometry in adolescent girls and its impact on sports bra design. A larger-scale replication study should be conducted in the future to gain a more comprehensive understanding of the needs and preferences of adolescent girls.

6. Acknowledgement

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