Breast Geometry and Sports Bra Design Study for Adolescent Girls

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Abstract

Breast measurement presents a complex challenge in the design of sports bras, particularly for adolescent girls whose bodies are rapidly changing. This study aimed to explore breast anthropometry among adolescents. A survey involving 23 girls aged 10 to 14 assessed their understanding of bra-related problems. In comparison, a wear trial with 7 girls sized 30AA to 32A evaluated their preferences through five bra conditions, 3D scanning and questionnaires. The study revealed a significant knowledge gap, with only 8.7% having had a bra fitting and less than half knowing how to determine their bra size. Notably, 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). The findings suggest a need for breathable fabrics in the upper bust while a preference for a stretchable underband to accommodate body growth. These results highlight the need to design sports bras tailored to the unique needs of adolescent girls, providing designers with critical insights into the necessary features and dimensions for optimal comfort during physical activity.

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

1. Introduction

Sports participation has a strong and positive impact on physical and mental health, which has led to an increasing number of women becoming active in recent years. Promoting an active lifestyle, the global sports bra market has been growing and recorded a revenue of US$43.7 billion in 2020, expected to reach US$93.7 billion by 2027 [1]. The statistics also indicate the increasing demand for sports bras in different regions, including the United States (US) and the United Kingdom (UK), but especially the Asia-Pacific region [2, 3]. In China, 83.9% of women wear a sports bra during physical activity, significantly higher than in the UK at 67.2% [2]. Despite the importance of proper breast support for active females, problems of wearing ill-fitting bras and inadequate bra designs are frequently reported. The high occurrence of breast pain during sports activities also implies that current sports bra designs are not sufficiently catering to the needs of all active women. 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 [4]. This is especially crucial for adolescent girls, whose bodies are still growing and developing with changes in body shape geometry and different needs for bra fit and breast support.

In the design of well-fitted sports bras, breast measurement is one of the most challenging aspects due to the deformability of breast tissues and the variety of profiles of breasts [5]. This complexity is heightened when considering the specific needs of adolescent girls. They are self-conscious of their body image, particularly feeling embarrassed about excessive breast movement during exercise. Tank tops and/or camisole tops that adolescents traditionally wear for exercise usually lack suitable breast support, protection and shaping. At the same time, the sizes are relatively

vague, such as small, medium, and large. To the best of our knowledge, there has been no comprehensive research into the body and breast shapes of adolescent girls about the design of sports bras. Further research is strongly recommended to fill this knowledge gap. This study aims to investigate the breast measurements of adolescent girls, providing valuable information for bra designers to create optimal designs for comfort during physical activities.

Adolescence is a period of rapid physical, cognitive and psycho-social growth. Research has shown active adolescents better perceive life and improve physical, mental, social, and emotional health [6]. The World Health Organization also suggests that adolescents engage in 60 minutes of moderate to vigorous exercise daily [6]. However, 85% of adolescent girls do not meet the recommended level of physical activity, often due to breast issues [7]. In the United Kingdom, 76% of girls reported that their breasts and related bouncing during exercise are a barrier to their participation in physical activities, which is more prevalent in larger-breasted girls [8]. Their concerns also include breast discomfort, lack of bra support, and embarrassment when getting changed due to exposure of their breasts or bras. As compared to daily outerwear, bras are more personal and individualised. Personal characteristics, such as age, body shape and cultural background, influence its use. As a unique group of consumers, adolescent girls have specific needs and preferences for sports bras due to their breast growth and changes in figure during puberty, as well as perceived wear comfort. Commercial sports bras designed for active women may not meet these adolescents' needs, leading to repeated problems with bra fit and breast support during exercise. 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 [9]. 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.

As shown above, adolescents have unique needs for bra fitting and breast support. When their breasts grow, they may also experience tenderness or soreness. They are often self-conscious about their bodies, particularly about excessive breast movement during exercise. This study aims to evaluate the fit, support, and function of sports bras for adolescent girls and to provide recommendations for improving the design of sports bras to ensure optimal fit, comfort, and protection during sports activities.

2. Method

This study employed a mixed-method approach, incorporating qualitative and quantitative research techniques, and was structured in two phases. The initial phase was dedicated to exploring adolescent girls' specific requirements and preferences regarding sports bras and identifying the common challenges they might encounter in selecting and fitting sports bras. This was achieved by administering a detailed questionnaire designed to capture a wide range of experiences and perspectives. The subsequent phase, Stage 2, focused on the examination of the breast anthropometry of adolescent girls, which is critical for the tailored design of sports bras that meet their unique physical needs. This phase involved a practical wear trial, allowing for the collection of precise data on fit, comfort and support, which are essential parameters in developing functional and comfortable 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 when designing sports bras for 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), under bust and full bust measurements, is provided in Table 1.

2.2 Data Collection

In the initial phase of the study, a comprehensive survey was disseminated amongst 23 adolescent participants to understand their habits, attitudes and knowledge concerning bra selection. The objective was to identify the factors influencing their choices in sports bras. In phase 2, the research introduced a standardised 2-minute Zumba dance

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/m2)	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)

routine as part of the wear trial. This exercise was specifically chosen to stimulate an active scenario, allowing participants to assess the performance of the bra under physical stress. Subsequently, participants were asked to complete a questionnaire using a 10-point Likert scale to rate their experience, with "1" indicating the lowest level of satisfaction and "10" representing the highest. The questionnaire covered eight key aspects: post-exercise design satisfaction, ease of wear, pain experienced, level of support, overall comfort, fit, and the tactile sensation of smooth hand feel and sense of coolness. The respondents evaluated these criteria to provide valuable insights into the performance of the sports bras during the specified activity.

In this study, participants evaluated five bra conditions to assess their suitability for exercise. These included a camisole top (condition a) offering the least support, a soft bra (condition b) providing minimal coverage to mimic a bra-less state, a pullover racer back seamless knitted sports bra (condition c), an adjustable straight back cut and sewn sports bra (condition d), and an adjustable racer back cut and sewn sports bra (condition e), as shown in Fig. 1. The inclusion of the soft bra was particularly to serve as a control for comparison against the more supportive sports bras. A state-of-the-art full-colour three-dimensional (3D) scanner was employed to accurately capture the participants' breast anthropometry. The Artec Eva scanner boasts an impressive 3D resolution of up to 0.2 mm and an accuracy of up to 0.1 mm, ensuring highly precise measurements. Ten markers were strategically placed on the participants to facilitate the determination of breast shape. These markers aided in measuring seven critical 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 back curvature, and breast ptosis. The methodology is illustrated and listed in Fig. 2 and Table 2.

Table 2. Demographics of participants

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
Under bust (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	The point at the side of the neck and nipples

	connecting line between the point at the side of the neck and the nipple	
Breast ptosis (cm)	Vertical distance between nipple to IMF	Point on nipple and IMF

The circumferences of full bust, under bust, and upper bust are typically used as indicators to determine bra size. The curvature of the back is determined by an angle, with a smaller angle suggesting a more hunched back. Breast ptosis is categorised into four grades [10]. 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.

The use of 3D scanning technology marks a significant advancement over conventional soft tape measurement methods, offering accurate and consistent digital representations of the breast shape. Unlike traditional techniques, 3D scanning enables the acquisition of linear dimensions, such as point-to-point distance, circumferences, and angles [11]. In the context of this study, the scanning was conducted by skilled personnel to guarantee the integrity of the data. All measurements were subsequently processed and recorded by the same trained individual using reverse engineering software (Geomagic Design X, Artec Europe), further ensuring the reliability and uniformity of the results. The XYZ coordinates of the breast were aligned to secure precise measurements. To enhance the accuracy of the data, each measurement was taken twice, with the mean of the two readings being used for the final 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.

3. Results and Discussion

3.1 Difficulties in Sports Bras Selection

Adolescent girls are navigating the transition to regularly wearing bras. Yet, the critical need for comfort in these next-to-skin apparel is often neglected due to a scarcity of research focused on bra design. This study aims to provide insights into sports bra design, particularly emphasising the requirements of Chinese adolescent girls. In the initial phase of the research, 23 adolescent girls were surveyed to understand their bra selection habits and perspectives towards the topic. The findings indicated a significant reliance on parental involvement in bra selection, with 82.6% of the respondents having their bras chosen by their parents, suggesting a possible deficiency in their bra selection knowledge. A mere 8.7% had undergone professional bra fitting, indicating a potential lack of awareness or availability of such services. Amongst the participants, only 34.8% felt perplexed about breast and bra-related topics, highlighting the necessity for more conversations and education regarding these natural bodily developments and the significance of proper bra fit and selection. This is consistent with findings from a survey of 2,089 schoolgirls in the United Kingdom [8], where a similar need for education was identified. Around 43.5% of respondents expressed embarrassment when discussing related topics. Implementing interactive workshops in schools could be a strategy to improve acceptance and awareness [12], with the potential to yield positive outcomes in terms of psychological well-being and satisfaction. Additionally, 43.5% of participants reported discomfort while wearing a bra, underscoring the critical demand for developing more comfortable and well-fitted bra designs tailored to the needs of adolescent girls.

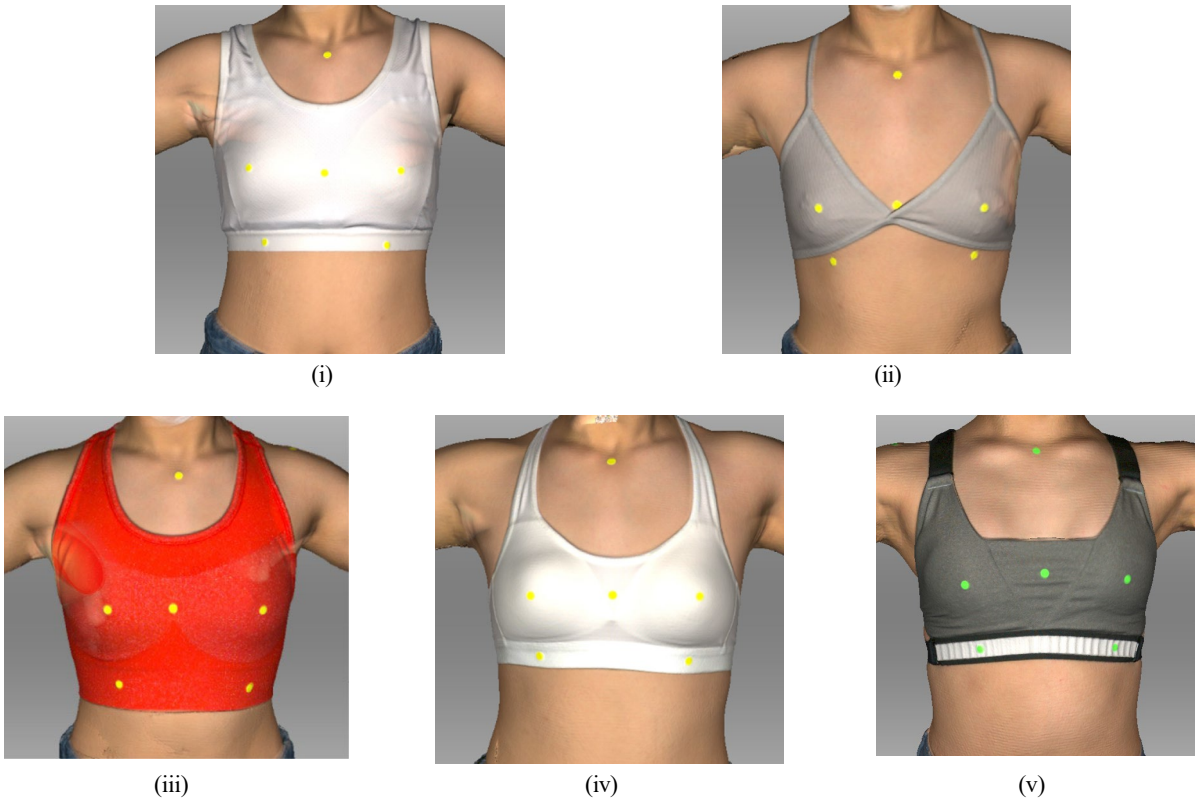
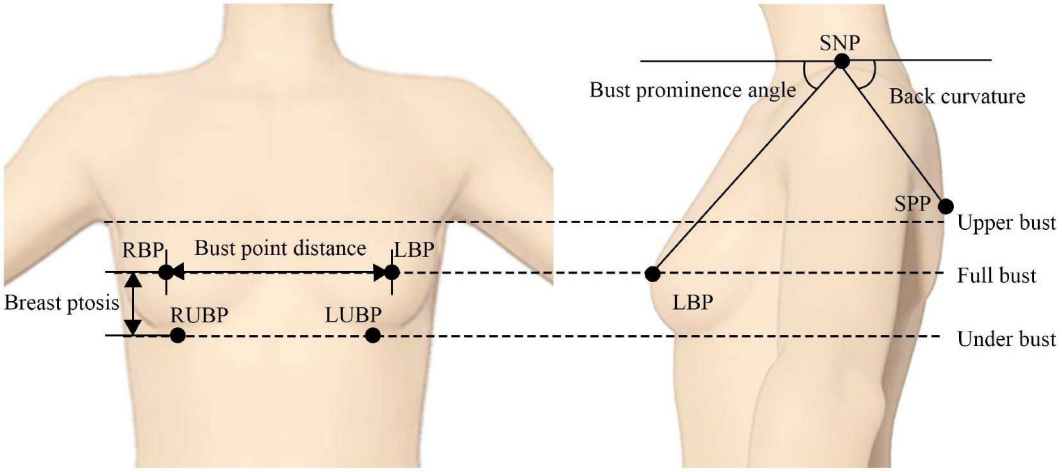


Fig. 1. 3D scanned image with landmarks of (i) a camisole top, (ii) a soft bra, (iii) a pullover racer back seamless knitted sports bra, (iv) an adjustable straight back cut and sewn sports bra, and (v) an adjustable racer back cut and sewn medium support sports bra



RBP: Right bust point
LBP: Left nipple
RUBP: Right underbust point
LUBP: Left underbust point
SNP: Side neck point
SPP: Scapula prominence point

Fig. 2. Illustration of the anthropometric measurements

3.2 Body Measurements and Subjective Perceptions of Bra Designs

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 negative correlation values indicate that as the measurements for the full bust, under bust, upper bust, and BP distance increase, 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.

Table 3. Demographics of participants

Criteria	Condition	Mean	SD	P	Criteria	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	7.07	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	

The upper bust measurement is also significantly associated with the level of "coolness" (r = -0.395 and p = 0.038), and the under bust measurement is associated with the level of "comfort" (r = -0.441 and p = 0.019). This 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. The fit of the under bust can significantly affect comfort. 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 [13]. Given the rapid growth of adolescents during adolescence, a highly stretchable underband with superior recovery and softness is preferred.

3.3 Body 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). 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 [14]. A study comparing the demographic data of 28 young females aged between 19 and 33 years old and 26 older females aged between 50 and 70 years old found significant differences in height, weight, and BMI between the two age groups [14]. 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 [14]. In this study, adolescents have a mean BMI value below 18.5 (Table 1), which is classified as underweight in Asian adults [15]. 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.

In stage 2, seven breast measurements were performed under five different bra conditions, with a soft bra simulating the bra-less condition. Table 4 presents the results of one-way ANOVA, with the calculated mean value and standard deviation. 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). 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 [16]. 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. A previous study found that ptosis is positively related to age, as breasts sag due to the loss of elasticity in the skin and Cooper's ligaments [14]. Changes in breast shape can significantly influence bra designs, and given the different shapes of breasts, adolescent bras should be specifically designed.

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). Ideally, the BP distance should be 21.6 cm [17]. However, in this study, the BP distance of the adolescent girls was under 20 cm, likely due to their younger age, lower weight, and height (Table 4). The gathering effect appears to be less important as a design feature.

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

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

	b	15.51	1.533	
BP Distance (cm)	c	15.46	1.086	0.043*
	d	14.83	1.718	
	e	16.46	0.598	

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

3.4 Breast Measurements and Features of Sports Bras

Results 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 (Table 4). 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 [18]. As shown in Table 4, the one-way ANOVA results provide the calculated mean value and standard deviation for these measurements across different sports bra conditions. The findings indicate that sports bras, especially those designed as pullover racer back seamless knitted sports bras, have a notable effect on lifting the breasts, which could potentially mitigate the extent of breast ptosis over time. This lifting phenomenon is attributed to the elasticity of the knitted structures, which snugly fit the body's contours and effectively provide uplift by securing the area just beneath the breasts. Taking the principles of breast biomechanics [19], sports bras are essential for offering the support needed to preserve the breasts' shape and position, thereby aiding in the prevention of discomfort and possible damage to breast tissue. Additionally, the study found that the distance between the BP distance tends to increase when participants wore an adjustable racer back cut and sewn sports bra (condition e). This suggests that such a design might cause the breasts to be positioned further apart, potentially compromising the aesthetic appearance of breast contours.

4. Conclusion

Through surveys and a wear trial, this study revealed the specific bra design requirements of adolescent girls in Hong Kong, highlighting notable deficiencies in breast education. The findings underscore the critical need to incorporate adolescents' distinct breast anthropometric measurements into sports bra design. Sports bras should integrate features such as highly stretchable underbands or adjustable knitted structures to accommodate the swift physical changes during adolescence. Such design enhancements could markedly improve comfort for adolescent girls during exercises, potentially boosting their engagement in physical activities. This study provides valuable insights into the relationship between breast anthropometry in adolescent girls and sports bra design, offering a valuable perspective for future product development. To expand upon these findings, a larger-scale study is recommended to provide a more exhaustive understanding of the needs and preferences of adolescent girls.

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