S5. Feedback report from elite athletes

- ***Project: Ergonomic Design of Sport-specific Sports Bras and Customisation for Female Athletes***

CONTENTS

Survey data available on request

Summary of the feedback report

- **Online Survey:** The initial online survey was conducted prior to the educational workshops.

Survey Population: **44 elite female athletes**, representing a variety of sports including rugby, rowing, wushu, swimming, fencing, equestrian, squash, and billiards. A structured online questionnaire was distributed to collect data on personal details, bra usage habits, and selection preferences.

- **Sports Bra Education Workshop & Fit Assessment:** Followed the initial survey.

Participants: **40 elite female athletes** from 8 sports teams.
Methodology: Hands-on workshops included educational sessions, professional bra size measurement, and individual fit assessments.

- **Feedback on two Customised Sports Bras:** After the design, prototyping, and distribution of two customised bras.

Participants: **17 elite female athletes** from **racket sports teams**.
Methodology: A feedback survey and objective biomechanical analysis were conducted to evaluate two newly designed sports bra prototypes.

Ergonomic Design of Sport-specific Sports Bras and Customisation for Female Athletes

Feedback from elite athletes

1. Background

Today, commercially available sports bras are mostly categorised based on 3 activity levels (low, medium and high impact activities) which do not consider sports activities, motion and differences in breast support requirements. Little is known about sports bra designs for an elite level of sport with consideration of vigorous body motion, posture changes and prolonged wearing. Due to poor breast/bra knowledge, bra discomfort, displacement and fit problems are frequently reported, **inevitably limiting free movement and negatively affecting the sporting performance of female athletes**.

With reference to the intervention study of sports bra prescription for elite UK female athletes preparing for the Tokyo Olympics and Paralympics (Scurr, Sanchez, & Jones, 2022), **we aim to: (1) address the sport-specific needs and fit assessments of sports bras to improve the bra knowledge and engagement for improved breast protection in sports; and (2) develop custom-designed sports bras for racket sports teams (such as badminton, squash, tennis, etc.) that precisely address the needs of athletes.** With reference to the needs of female athletes and sport-specific breast motion for bra support requirements, sports bras can also be custom-fit for other teams.

2. Method

2.1 Online Survey on the Use of Sports Bras

Firstly, online sports bra survey was designed to understand the needs around breast support, choice of brands and styles, problems with bra fit, preference of bra features and perceptions towards various sports bra designs amongst elite athletes.

The survey is divided into 3 parts: (1) personal details including age, height, weight, sports type, training routine and bra size, (2) bra usage for sports including breast pain issues and bra problems, and (3) sports bra selection preferences including bra purchasing habits and fitting experience.

2.1.1 Personal details of participants (athletes)

A total of 44 questionnaires were collected from female athletes. The profile of elite athletes in this study, in terms of age, height, weight, BMI, and sports type is presented in **Figures 1 to 8**. As shown, most athlete respondents are from the rugby team (38.6%) and rowing team (20.5%). Over 50% of them have 4-6 training sessions per week (**Figure 6**). Each session lasts at least 1.5 hours (**Figure 7**). Over 80% of athletes are not sure about their bra size or not confident they are wearing the correct bra size (**Figure 8**).

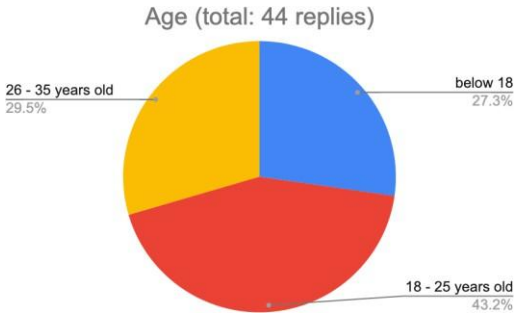


Figure 1 Age of participants

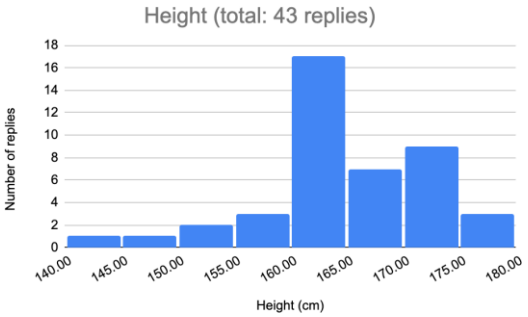


Figure 2 Height of participants

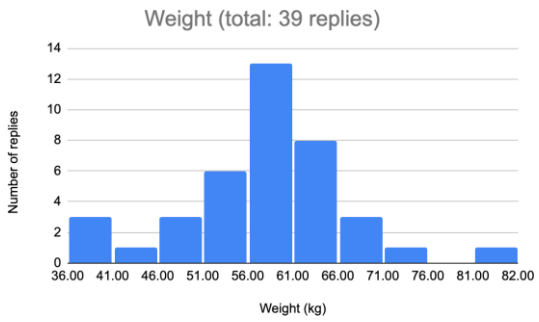


Figure 3 Weight of participants

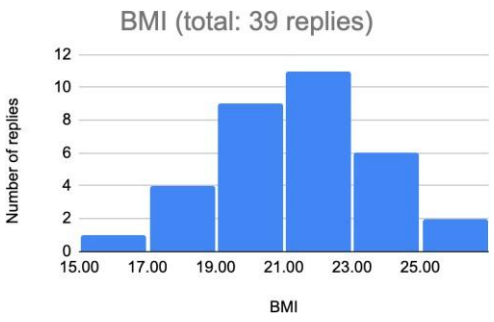


Figure 4 BMI of participants

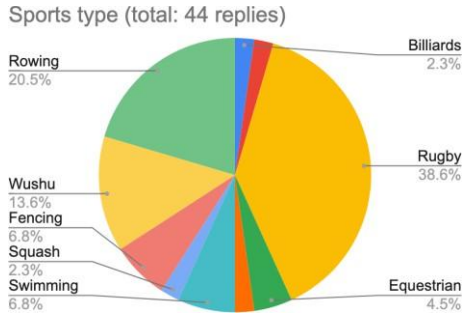


Figure 5 Sports type of participants

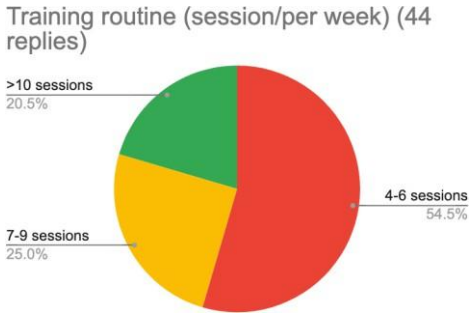


Figure 6 Training routine of participants

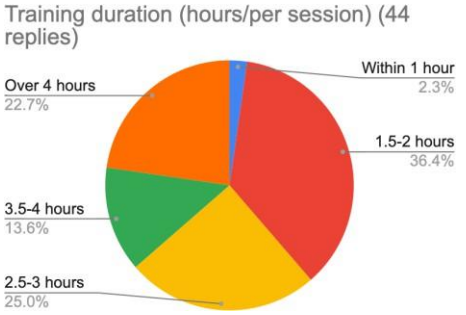


Figure 7 Training duration of participants

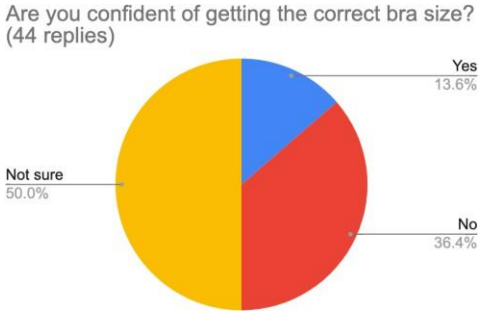


Figure 8 Bra size understanding of participants

2.1.2 Feedback on Bra Usage from Female Athletes

This survey has studied the sports bra usage situation for female athletes (**Figures 9 to 12**). 85.4% of female athletes would wear sports bras in training or competitions. Over 70% of athletes agree that wearing sports bras during exercise is important. Nevertheless, the average satisfaction rate of their own bras is **3.68** out of 5. 61% of female athletes have experience of bra fitting problems.

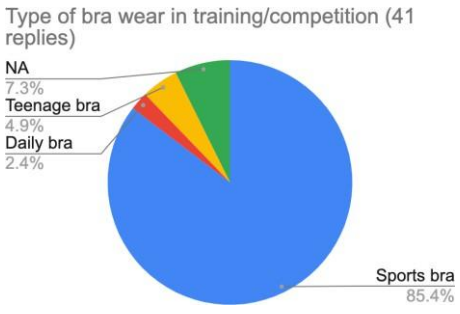


Figure 9 Types of bra wear for sports

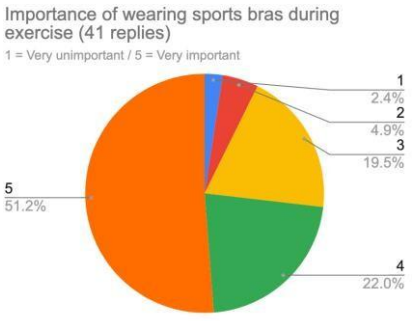
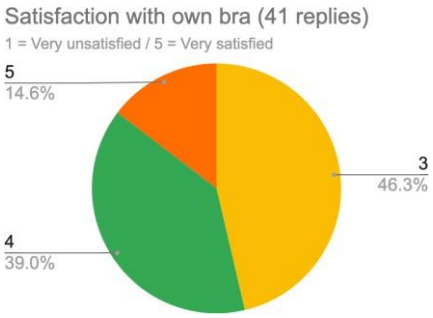


Figure 10 Importance of wearing sports bra



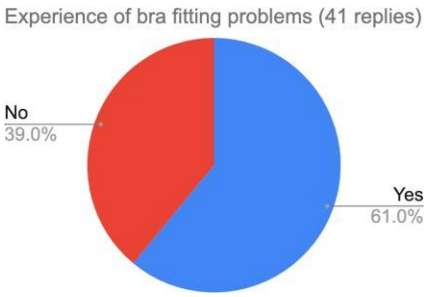


Figure 11 Satisfaction of athletes' own bra **Figure 12** Bra fitting problem experience

2.1.3 Sports Bra Selection Preferences of Female Athletes

The preference on sports bras amongst female athletes was also investigated. 78% of athletes most frequently purchase sports bras from sportswear brands. They usually have 4-6 sports bras in total for training/competition, while majority of respondents would not change their bra very often, they usually change it when it was worn for over 1 year. Over 85% of them do not have any professional bra fitting experience. The rating of design and aesthetics is the lowest, which means it is the least important requirement.

Their ratings on sports bra parameters in the Likert scale from 1 to 5 (1 is the least important, while 5 is the most important) are shown in Table 1. Bra **comfort** and **fit** are perceived as the most important parameters.

Table 1 Rating of the importance of different sports bra requirements

Sports Bra Requirement	Rating of importance					Mean (out of 5)
	1	2	3	4	5	
Breast support	7.3%	12.2%	22.0%	24.4%	34.1%	3.66
Design & aesthetics	7.3%	22.0%	29.3%	26.8%	14.6%	3.20
Fit	7.3%	2.4%	24.4%	17.1%	48.8%	3.98
Comfort	7.3%	2.4%	24.4%	14.6%	51.2%	**4.00**
Breathability	7.3%	4.9%	24.4%	24.4%	39.0%	3.83
Moisture wicking	4.9%	17.1%	19.5%	24.4%	34.1%	3.66
Total replies: 41; 1 = Very unimportant / 5 = Very important						

2.1.4 Summary

From the online survey, most female athletes do not know their correct bra size and are not familiar with the bra sizing system. Also, many of them have experienced bra fitting problems. Many athletes purchase sports bras most frequently from sportswear brands and are unfamiliar with the sports bras in lingerie brands. Most of them do not have any professional bra fitting experience, so they may not understand how to fit their bra well. Therefore, a sports bra education and fitting workshop is necessary for them to understand more about sports bras, know their bra size and how to choose a suitable bra with an appropriate fit.

2.2 Sports Bra Education Workshop

To improve athletes' understanding of sports bras, sports bra education workshops and individual bra fit assessments were designed for athletes. The workshop consists of three sessions: (1) introduce sports bra knowledge, including sports bra type and requirements for proper wear, (2) bra size measurement and selection of 2-3 bras based on professional recommendation and preference, and (3) personal fitting assessment of selected sports bra and athlete's own bra by bra fit specialists.

2.2.1 Flow of the Workshop

Athletes were firstly required to sign a consent form and provided a sports bra knowledge leaflet and bra fitting evaluation form. Education workshops include discussion on bra features, support levels, bra and breast problems, along with tailor-designed videos of bra issues (**Figure 13**). Information on breast size measurements, choice of bra size; the impact level classification and features of sports bras, including shoulder strap style, cup coverage, back style, etc; and the correct method to wear sports bra has been shared. With the help of professional bra fit specialists, each athlete has chosen 2-3 sports bras for fitting.

Figure 13 Sports bras education activity photos

Bra fit comments on their own sports bra and the selected 2-3 sports bras were given by a professional bra fit specialist. The overall fitting effect, looseness and tightness of the underband and shoulder strap, underarm and the support of the breast during the movement, etc., were assessed, professional and feasible suggestions to the athletes were also shared. At the same time, interface pressure was measured based on the principle of voluntary participation, including the shoulder point, the back underband point, the side seam, and the side underband point.

2.2.2 Analysis of Bra Samples

The key features of sports bras were introduced, including shoulder strap, bra cup, underband and back design. The influence of bra design features, sewing techniques and fabrications on breast support, breathability and comfort of sports bras were discussed. The typically used **back designs**, including racer back, cross back and scoop back were presented (**Figure 14**).

(a)Racer back (b) Cross back (c) Scoop back

Figure 14 Three back designs typically used in sports bras

In view of **shoulder straps**, the width of the shoulder straps could affect the pressure on the shoulders as well as the overall support with reduced breast displacements during physical activities. Sports bras with shoulder strap widths from 1.2 cm to 4.0 cm, along with their cushioning performance were reviewed and discussed (**Figure 15**).

1.2 cm 2 cm 2.5 cm 3 cm 3.5 cm 4 cm

Figure 15 Different widths of shoulder straps

Additionally, shoulder strap adjustment design is a key feature for improving the fit of sports bras. Sports bras with 5 different levels of adjustments in shoulder straps were introduced (**Figure 16**). For bra cups, 4 cup features, including no cup, removable cup, fixed cups and molded cups with holes were presented (**Figure 17**). It is noted that the molded cups provide better breast support, while the 3D shape and curvatures of molded cup are strongly

associate with the fit of sports bras. (**Figure 18**).

Figure 16 Different adjustments and positions of the shoulder straps

Figure 17 Four cup styles

Figure 18 Different cup shapes and hole sizes

Sports bras made of fabrics in different thicknesses and compositions were reviewed (**Figure 19**). For the underband, a range of width from 2 cm to 6 cm (**Figure 20**) and different elastic band materials (**Figure 21**), such as arbitrary fabric, stretch fabric, double elastic band, highly elasticized, arbitrary & elastic band and so on were presented.

(a) double mesh (b) half mesh (c) thin fabric (d) heavy fabric (e) hot pressed fabric (f) knitted

Figure 19 Different fabrics used in sports bras

Figure 20 Different widths of underband

Figure 21 Different materials of underband

Amongst the racer-back designs, the dorsal hook (**Figure 22**) is a key structural design feature. It is noted that the width of the dorsal hook has major influence on position of the neckline (neck drop) and shoulder straps, arising from the tension changes (**Figure 23**).

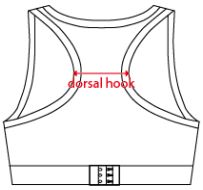


Figure 22 dorsal hook structure

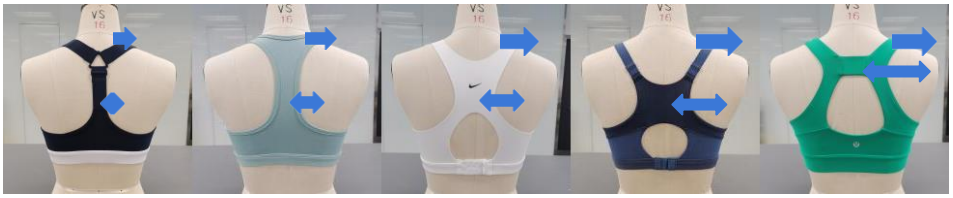


Figure 23 The change of the sports bras

A total of 24 sports bra styles (in range of full sizes available in the commercial market) with different design features were discussed in the bra education workshop (**Table 2**).

Table 2 List of sports bra samples adopted in bra education workshops

Style & code	Front Features	Back Features	Size & color	Main Fabric
 A01	Compression bra style; Medium impact level; Removable cup pads	Shoulder strap is non-adjustable; Underband is non-adjustable; Racer back style	70B(Black) 75B(Black) 80D(Black) 85D(Black)	89% Polyester + 11% Spandex
 A02	Combination bra style; High impact level; Fixedpads; ZIP front	Shoulder strap is adjustable (front part); Cross back style	70B(Black) 75B(Black) 80C(Black)	79%、 Polyester +21% Spandex
 A03	Combination bra style; High impact level; Fixed molded cup pads	Shoulder strap is adjustable; Underband is adjustable with 4×3 H&E; Cross back style	75B(Black)	79% Polyester + 21% Spandex
 A04	Compression bra style; High impact level; Removable cup pads	Shoulder strap is adjustable (back part); Underband is non-adjustable; Scoop back style	75B(White)	64% Polyester + 36% Elastane

 AT01	Combination bra style; High impact level; Fixed molded cup pads	Shoulder strap is wide non-adjustable; Cross back style (Double Strap)	84A(Green) 88A(Purple) 92A(Green) 96A(Black)	75% Polyamide + 25% Spandex
 AM01	Combination bra style; High impact level; Fixed molded cup pads	Underband is adjustable with 3×2 H&E; Cross back style; Overall use of mesh fabric	85A(Purple) 90B(Yellow) 90C(Purple)	67% Polyamide +33% Elastane
 D01	Combination bra style; High impact level; Fixed molded cup pads; ZIP front	Shoulder strap is adjustable (at shoulder); Racer back style	65C(Blue) 70C(Pink) 75C(Dark Blue) 80C(Black) 85C(Purple)	91% Polyester +9% Spandex
 G01	Compression bra style; High impact level; Removable cup pads	Shoulder strap is non-adjustable; Scoop back style; Wide underband	80C(White) 80E(White)	78% Polyester +22% Elastane
 G02	Compression bra style; Low impact level; Removable cup pads	Shoulder strap is non-adjustable; Cross back style	70D(Black) 75D(Green)	81% Nylon + 13% Polyester + 6% Elastane
 H01	Encapsulation bra style; Medium impact level; Fixed molded cup pads	Shoulder strap is non-adjustable; Underband is adjustable with 3×2 H&E; Cross back style	70B(Pink) 75B(Black) 80C(White)	63% Nylon + 37% Spandex

 H02	Compression bra style; Medium impact level; Fixed molded cup pads	Shoulder strap is non-adjustable; Underband is non-adjustable; Racer back style; One-piece knit	70B(Pink) 75B(Green) 80C(Purple)	86% Polyester + 14% Spandex
 H03	Combination bra style; High impact level; Fixed molded cup pads	Shoulder strap is adjustable; Underband is wider and adjustable with 4×3 H&E	75B(Black) 80B(Pink)	62% Nylon +38% Spandex
 HO3-2	Combination bra style; High impact level; Fixed molded cup pads	Shoulder strap is adjustable; Underband is wider and adjustable with 4×2 H&E	80B(Blue)	62% Nylon +38% Spandex
 H04	Combination bra style; Medium impact level; Fixed molded cup pads	Shoulder strap is adjustable; Underband is adjustable with 4×2 H&E; Racer back style	75B(Dark Blue) 80B(Dark Blue)	79% Nylon + 21% Spandex
 LU01	Compression bra style; Medium impact level; Removable cup pads	Shoulder strap is non-adjustable; Race back style; Wide underband	84A(Apricot) 88A(Green) 92A(Apricot)	77% Nylon + 23% Spandex
 MS01	Encapsulation bra style; High impact level; Fixed molded cup pads	Shoulder strap is adjustable; Underband is adjustable with 3×2 H&E; Cross back style	75B(Rose red) 80C(Rose red)	64% Polyamide +19% Polyester + 18% Spandex
 MS02	Combination bra style; High impact level; Fixed molded cup pads	Shoulder strap is adjustable; Underband is adjustable with 3×2 H&E; Scoop back	70B(Black) 85B(Black)	66% Polyester + 20% Polyamide+14 % Spandex

		style		
 MS03	Compression bra style; High impact level; Fixed molded cup pads; ZIP front	Shoulder strap is non-adjustable; Race back style	70C(Black) 85B(Black)	74% Polyester + 14% Spandex + 13% Polyamide
 N01	Combination bra style; High impact level; Fixed molded cup pads	Shoulder strap is wide adjustable; Underband is adjustable with 4×3 H&E; Scoop back style	80A(Black) 84A(Black) 88A(Purple)	64% Polyester + 36% Spandex
 N02	Encapsulation bra style; Low impact level; Fixed molded cup pads	Shoulder strap is narrow adjustable; Underband is adjustable with 4×2 H&E	76A(Blue) 80A(Blue) 84A(Blue)	74% Polyester + 26% Spandex
 N03	Combination bra style; High impact level; Fixed molded cup pads; ZIP front	Shoulder strap is adjustable; Underband is adjustable with 3×2 H&E; Racer back style	76A(White) 80A(Blue) 84A(White) 88A(Blue)	64% Polyester + 36% Spandex
 N04	Compression bra style; Medium impact level; Fixed molded cup pads	Shoulder strap is non-adjustable; Race back style	76A(Pink) 84A(Cyan) 88A(Cyan)	72% Polyester + 28% Spandex
 SB01	Compression bra style; Medium impact level; Removable cup pads	Shoulder strap is adjustable; Racer back style	80A(Grass green) 88A(Black) 96A(Dark Blue) 100A(Green)	62% Polyamide + 38% Spandex

 W01	Combination bra style; High impact level; Fixed molded cup pads	Shoulder strap is non-adjustable; Cross back style	75C(Black White) 80B(Black White) 80D(Purple)	80% Nylon + 20% Spandex
 W02	Compression bra style; Medium impact level; Removable cup pads	Shoulder strap is narrow (2 straps); Underband is adjustable with 3×3 H&E	L(Black) LL(Blue)	82% Nylon + 18% Spandex

2.3 Feedback Survey on Bra Education Workshop & Fit Assessment

2.3.1 Participants (female athletes)

A total of 40 athletes participated in the workshop from 8 sports teams, their profile is presented in **Table 3** below.

Table 3 Number of participants and sports programs

Sports team	Participants number	Notes
Rugby	17	Adults
Swimming	3	Under 18
Wu Shu	4	Under 18
Karate	1	Adults
Fencing	3	2 Under 18
Equestrian	2	Adults
Squash	1	Adults
Rowing	9	Adults
Total	**40**	

2.3.2 Feedback rating results

All athletes gave positive feedback on the workshop, which helped them improve their understanding of sports bras and 97.4% of athletes were satisfied with the workshop, which gave them good advice on choosing a correct sports bra. Some comments are shown below:

"The bra education workshop was eye-opening. I finally understand how to choose the right sports bra for my needs." – **So, Rugby Player**

"I learned so much about the importance of proper bra fit. The specialist provided personalised advice that I can use to choose the right sports bras in the future." – **Tse, Rugby Player**

"Getting a professional fitting was amazing. She took the time to explain everything and made sure I found the perfect fit. I am now more confident to find the right sports bras for my specific needs and activities." – **Cheung, Rowing Player**

"The professional bra fit assessment was thorough and insightful, and I feel much better equipped to select the right sports bras in the future." – **Chan, Wu Shu Player**

The mean satisfaction scores for the fit assessment session and workshop education were 4.6 and 4.7 (out of the maximum of 5), respectively (**Table 4**).

Table 4 Sports Bra Education Workshop & Individual Fit Assessment Feedback Survey

Question 1: **(100%)**	Yes		No		
Do you think this workshop can help the understanding of sports bras?	39		0		
Question 2: **(Mean: 4.6/ 5)**	1	2	3	4	5
To what extent, are you satisfied with the bra fitting session?	0	0	1	13	25
Question 3: **(97.4%)**	Yes		No		
Do you think this workshop is helpful for your choice of sports bra, bra size and wearing appropriate breast support in sports in future?	38		1		
Question 4: **(Mean: 4.8/ 5)**	1	2	3	4	5
Overall, are you satisfied with this workshop?	0	0	0	8	31

Note: one missing; 1=very unsatisfied; 5=very satisfied

2.3.3 Bra fit issues

According to the results, up to 69% of the athletes' own bras showed poor fit (**Figure 24**). Amongst the participants, 59% of them had improved bra fit after the fitting session. For athletes who have poorly-fit issues, personal bra advice and suggestions on bra choice and features were given respectively (**Figure 25**).

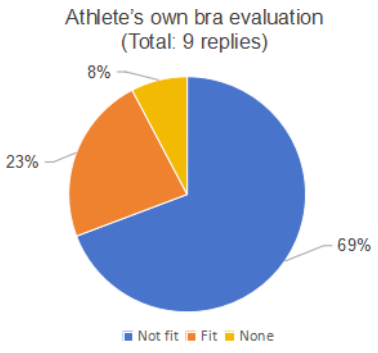


Figure 24 Athlete's own bra evaluation

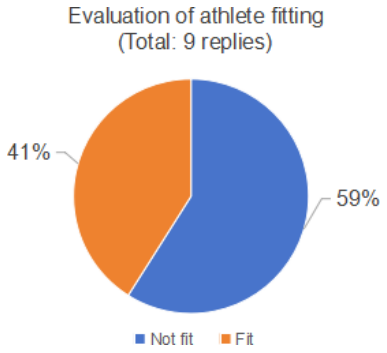


Figure 25 Evaluation of athlete fitting

It is noted that the athletes' own sports bras were generally loosely fit, which may be explained by the high pressures and discomfort induced by sports bras. Fit problems were generally caused by the shoulder straps and underbands (**Figure 26**). The loose-fitting issues observed from shoulder straps (42.5%), underband (22.5%) and the corresponding problem

of underband riding up (12.5%) may result in bra displacement and inadequate breast support, leading to excessive breast motion during sports activities (**Figure 27**).

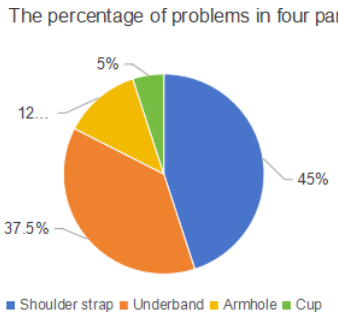


Figure 26 The percentage of problems in four parts

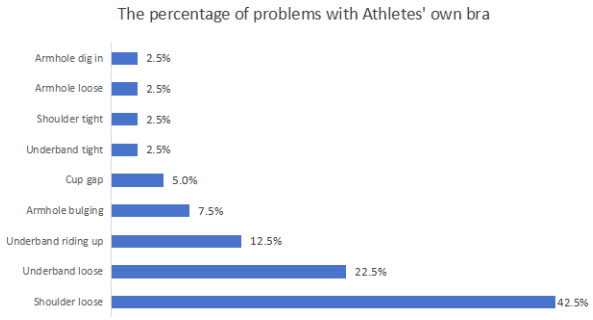


Figure 27 The percentage of problems with Athlete's own bra

2.3.4 Summary

A total of 40 athletes participated in the workshop from 8 sports teams. The workshop provided athletes 24 styles, totaling 11 brands of sports bras. Firstly, the workshop gave athletes a basic knowledge and understanding of sports bra knowledge and helped them select the suitable sports bras. From the results of athlete feedback, it can be found that 100% of athletes agreed that the workshop was helpful; and 97.4% of them received useful advice on the sports bra choice; the satisfaction scores for the bra fit assessment and workshop education were 4.6 and 4.7 respectively.

With reference to the badminton-specific sports bra prototype developed by the team, the design criteria established with respect to the movement of the upper body in racket sports training and competitions, as well as the data obtained from surveys and bra assessments in the workshop, suitable design features of sports bra prototypes were devised. The overall design process is presented in **Figure 28** below.

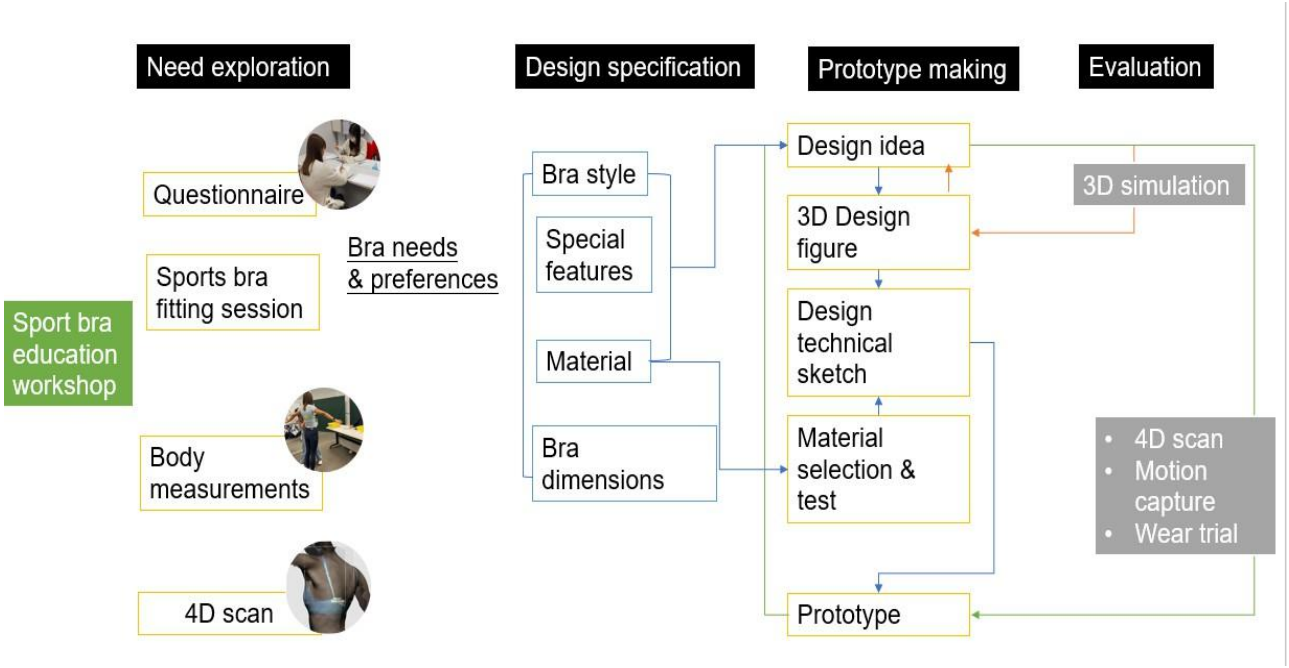


Figure 28 Design process of tailored sports bras for racket teams

2.4 Custom-designed sports bras for racket sports team

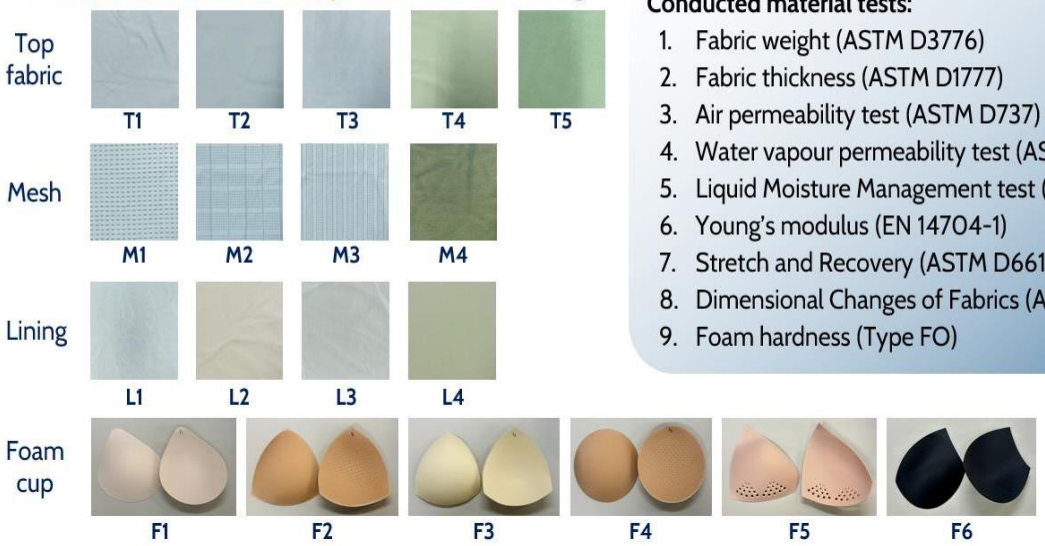
Given the asymmetrical nature of these sports, the incorporation of wide shoulder straps with specialized designs for left-handed or right-handed players enhances performance. These designs ensure unrestricted shoulder and arm movement on the dominant side, while simultaneously providing improved support and fit on the non-dominant side to prevent the shoulder strap from slipping. Two designs of tailored sports bra for racket team were proposed (**Figure 29**). This includes the use of asymmetric neckline panel with bias-cut and asymmetric back panel for more flexibility to dominant-hand side; as well as asymmetric material at back panel to provide more flexibility to dominant-hand side.

Figure 29 Two tailored sports bra designs with asymmetrical features for racket teams: Bra A (top) and Bra B (bottom)

A series of sports bra prototypes were designed and developed for initial fitting. With the help of professional bra fit specialist, technical advice was collected and modifications in patterns, fabrications and sizes were made. Extensive materials tests were conducted that top fabrics, mesh fabric, lining, foam cups, trims and fasteners with the optimal mechanical and thermal properties were selected for bra prototyping.

Comprehensive fabric tests to analyse the thermal comfort properties of the fabric materials which affect wearing comfort perception and skin surface temperature of the athletes.

Total 13 fabrics and 6 foam cups are sourced for testing



Conducted material tests:

1. Fabric weight (ASTM D3776)
2. Fabric thickness (ASTM D1777)
3. Air permeability test (ASTM D737)
4. Water vapour permeability test (ASTM E96)
5. Liquid Moisture Management test (AATCC 195)
6. Young's modulus (EN 14704-1)
7. Stretch and Recovery (ASTM D6614)
8. Dimensional Changes of Fabrics (AATCC 135)
9. Foam hardness (Type FO)

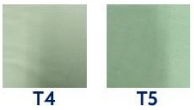
Choice of outer layer fabrics

- Mainly applied as the outer layer at the shoulder, breast, and back
- Main concerns: Anti-UV properties (sun protection for outdoor activities) and tensile properties (stretchability for movement and support)

Comparison of top fabrics			T1	T2	T3	T4	T5
Anti-UV Properties	Fabric weight (g/m²)		136.43	181.92	165.99	318.46	239.61
	Fabric thickness (mm)		0.433	0.460	0.407	0.740	0.660
Tensile Properties	Tensile Strain At Maximum Load (Stretch) (%)	Warp	196.1	70.55	138.66	129.55	87.99
		Weft	190.77	194.71	96.4	163.26	179.21
	Growth (%)	Warp	14	7.18	8.97	8.58	9.14
		Weft	13.09	33.86	5.45	16.41	21.7
	Recovery (%)	Warp	92.86	89.82	93.52	93.38	89.61
		Weft	93.14	82.63	94.35	89.95	87.88
	Young's Modulus (Mpa)	Warp	0.1906	0.5167	0.2802	0.1546	0.2332
		Weft	0.2089	0.2945	0.4669	0.2005	0.1858

- T2, T4, and T5 have **good anti-UV properties** (weight over 170g/m²)
- T4 and T5 have **better flexibility and recovery** than T2

Results: T4 and T5 are selected.



Choice of Mesh fabric

- Mainly applied at the **breast** and **back** (most sweated areas)
- Main concerns: **moisture-wicking ability, breathability,** and **stretchability**

Comparison of mesh fabrics			M1	M2	M3	M4
Moisture Permeability Properties	Accumulative One-Way Transport Index	Unwashed	5	1	5	3
		Washed	5	1	5	3
	Bottom Absorption Rate	Unwashed	5	1	5	3
		Washed	4	1	5	4
Air Permeability Properties	Water Vapor Transmission Rate (g/h·m²)		34.958	36.074	34.034	36.421
	Air permeability (kPa s/m)		0.088	0.057	0.12	0.003
Tensile Properties	Tensile Strain At Maximum Load (Stretch) (%)	Warp	87.21	61.28	107.2	128.71
		Weft	114.64	79.49	141.94	87.78
	Growth (%)	Warp	10.78	5.19	7.75	9.14
		Weft	17.87	5.73	38.7	6.25
	Recovery (%)	Warp	87.65	91.49	92.76	92.89
		Weft	84.4	92.79	72.74	92.87
	Young's Modulus (Mpa)	Warp	0.4380	0.7018	0.2982	0.2758
		Weft	0.4195	0.6939	0.2864	0.3824

- **M1, M3, and M4** have **good performance in moisture permeability properties**
- **M4** has **better air permeability** than other mesh
- **M4** has **better flexibility and recovery** than other mesh

Results: M4 is selected.

M4

Choice of foam cups

- Important component to **provide breast support** and **protection**
- Lower breast is one of the **most frequently sweated areas**
- Main concerns: **thickness, hardness, cup shape** and **air permeability**

Foam properties	F1	F2	F3	F4	F5	F6
Thickness (mm)	5.180	3.600	5.744	3.136	3.464	6.100
Hardness	24.0	63.5	44.9	55.0	61.8	45.3
Air permeability (kPa s/m)	0.482	0.302	0.214	0.250	0.131	0.466

- **F1: softest cup with poorest breathability** → cannot provide enough breast support
- **F2: hardest cup** → may not fit well with breast
- **F3: triangular cup shape** → cannot provide enough breast support and coverage
- **F4: thinnest cup** → cannot provide enough support and coverage for nipples
- **F5:** has the **highest air permeability** → **good breathability**
- **F6:** has **adequate hardness and cup shape** → soft and can **provide enough support**

F5

F6

Results: F5 and F6 are selected.

With reference to the feedback of athletes throughout repeated bra assessments, sports bra specifications for the 2 prototypes were formulated. The most desirable bra style, choice of fabrication materials, elastic bands, shoulder straps, cup padding, etc. were precisely identified for optimal bra fit, comfort, support and aesthetics. The choice of seam types, structures, stitch types and seaming approach in relation to elasticity, comfort, silhouette, aesthetics, scale of production, etc. were also determined.

Over 600 sports bras in sizes 160, 165 and 170 were produced and prescribed to female athletes in racket sports teams. Bra prescription and personal feedback from individual athletes were conducted.

2.5 Feedback Survey on Tailored Sports Bras

2.5.1 Participants

A feedback survey was designed to collect comments on the two tailored sports bras from female athletes. The athletes were invited to complete the survey at the end of the bra prescription and fit sessions. Results obtained from a total of 17 athletes (in racket sports teams of badminton, squash, and tennis) were collected. Most of the respondents (94.1%) were right-handed dominants, fitting bra sizes 160 (S) and 165 (M).

2.5.2 Feedback on the 2 tailored sports bras

Results indicated that both tailored sports bras were well perceived by the female athletes. Amongst the 17 respondents, 52.9% preferred Bra Style B (the white colour design). However, it is noted that one respondent gave a negative rating on both bra designs due to fit issues.

Subjective ratings on fabric comfort, pressure comfort; and bra fit were collected by using a Likert scale from 1 to 9 (1 being the least desirable and 9 being the most desirable). As shown in **Table 5**, the softness, tactile sensation and tingling of fabrics and trims used for the 2 bras were positively perceived by respondents with mean ratings ranging from 6.5 to 7.2. **Table 6** presents the subjective ratings on bra pressures, which impact comfort perceptions, with mean ratings ranging from 5.4 to 7.2. Bra A (the purple colour design) was perceived as "more comfortable" than white design, especially in areas such as the shoulder strap, side wings, and back design (featuring adjustable hooks-and-eyes). Some comments are shown below:

"*I felt less restricted compared to my usual sports bra.*" – **Ng, Tennis Player**

"*I noticed a marked differences in my shoulder and right back movement. The asymmetrical design helps in preserving range of motion.*" – **Leung, Badminton Player**

"*The purple bra was incredibly comfortable, especially around the shoulder straps and underband. It felt like tailor-making for me*" – **Ng, Badminton Player**

"*While the white bra was a bit harder to put on, once it was on, it provided good support without feeling too tight.*" – **Cheung, Badminton Player**

"*The fabrics used in both bras were soft and breathable. I didn't experience any irritation or discomfort.*" – **Wong, Tennis Player**

Table 5 Ratings on bra fabric and trim performance

		
Softness of fabric (rigid – soft)	7.0	6.5
Tactile sensation of the fabric (Rough – Smooth)	7.0	7.0
Sensation of fabric tingling (Itchy – Comfort)	7.2	7.2

Table 6 Ratings on bra pressure comfort

		
Shoulder strap	7.2	5.4
Side wing	6.7	5.8
Bra pad	6.0	6.3
Under band	6.3	6.0
Back	7.0	5.6
Overall	6.8	6.0

2.5.3 Bra fit issues for elite athletes

The fitting of the 2 bras has been generally satisfactory, with mean ratings of 6.08 across various regions, including shoulder straps, underband, bra pad, overall wearability, etc. For the purple design, the bra cups are slightly larger, which may be due to differences in the body structure and breast shapes between elite athletes and university sports team athletes (who were invited for initial fitting of bra prototypes). It is noteworthy that intense training can lead to changes in body structure, increased muscle mass and reduced body fat percentage, depending on the sport. These changes in breast components and glandular tissue stiffness may reduce breast deformations during movement, altering the needs of breast support. To provide tailored breast support and fit for female athletes, an accurate representation of the pose-related shape variations due to different body structures and sports conditions is essential in analysis of breast motions. Suitable bra features and paddings with superior fit and cushioning are required to offer precise breast protection against breast displacements with less compression for optimal comfort.

Nevertheless, participants who found a good fit with the encapsulated bra cups provided positive feedback, highlighting the fit, shape, comfort and easy of wear. For the white design, the compression style (pull-over) is slightly more challenging to put on and take off compared to the purple one. While the perceived bra pressure is generally higher, leading to lower scores in pressure comfort, it still offers a unique option for those seeking a compression fit.

By using **asymmetrical bra features and materials**, the two designs aim to allow unrestricted shoulder and arm movement on the dominant side, while simultaneously providing improved support and fit on the non-dominant side to prevent the shoulder strap from slipping.

2.5.4 Biomechanical analysis of Tailored sports bras

Apart from the subjective ratings, objective evaluation of the sports bra performance was also investigated. In tennis, internal and external rotation of the shoulder are strongly associated with ball velocity and performance (Elliott, 2006; Roetert, Ellenbecker, & Reid, 2009). Parameters such as bra support and range of motion with bras were recorded and compared against selected commercial sports bras. This allows for the identification of necessary design modifications to enhance performance and comfort.

A total of 6 female athletes from the University Badminton and Tennis teams were invited to participate in this study. A series of laboratory experiments were conducted, including 4D body scanning and motion capture synchronised with a force plate to characterise and compare their biomechanical performance under various bra/breast conditions (**Figure 30**). The overall performance of the 2 bras was compared with that of a commercial sports bra and a braless condition.

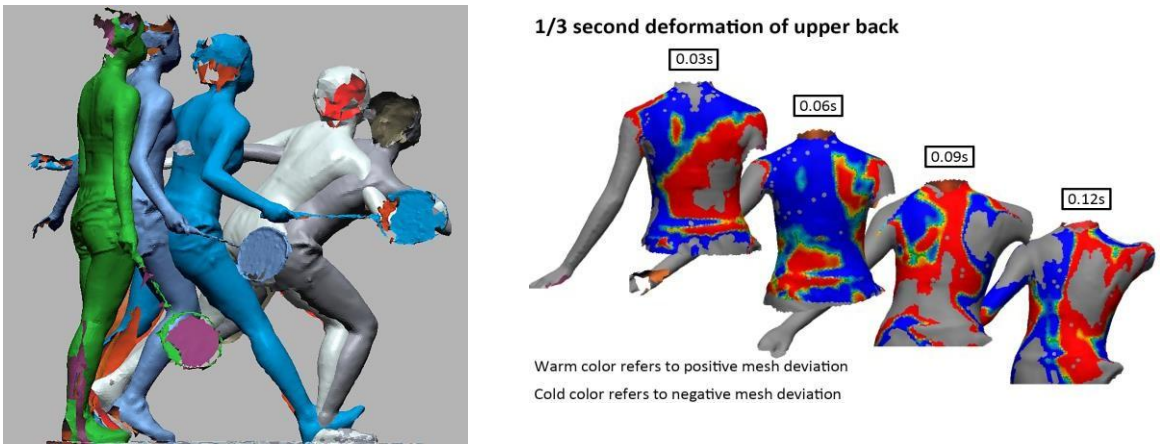


Figure 30 Scanning and motion capture to provide additional information for biomechanical analysis

Results indicated that with the sports bra, the range of motion and power at elbow and shoulder were limited, the angles of elbow and shoulder were reduced from 0.5-11.7 degree, the power of elbow and shoulder was reduced from 0.1-0.2 W/kg (**Figure 31**). However, as compared to commercial sports bra, wearing the 2 sports-specific bras for racket sports athletes showed less limitation on these variables. The greater shoulder angle range is attributed to the bra's asymmetrical panel, which alters the direction of fabric elongation, and an asymmetrical back panel made of stretchy mesh fabric.

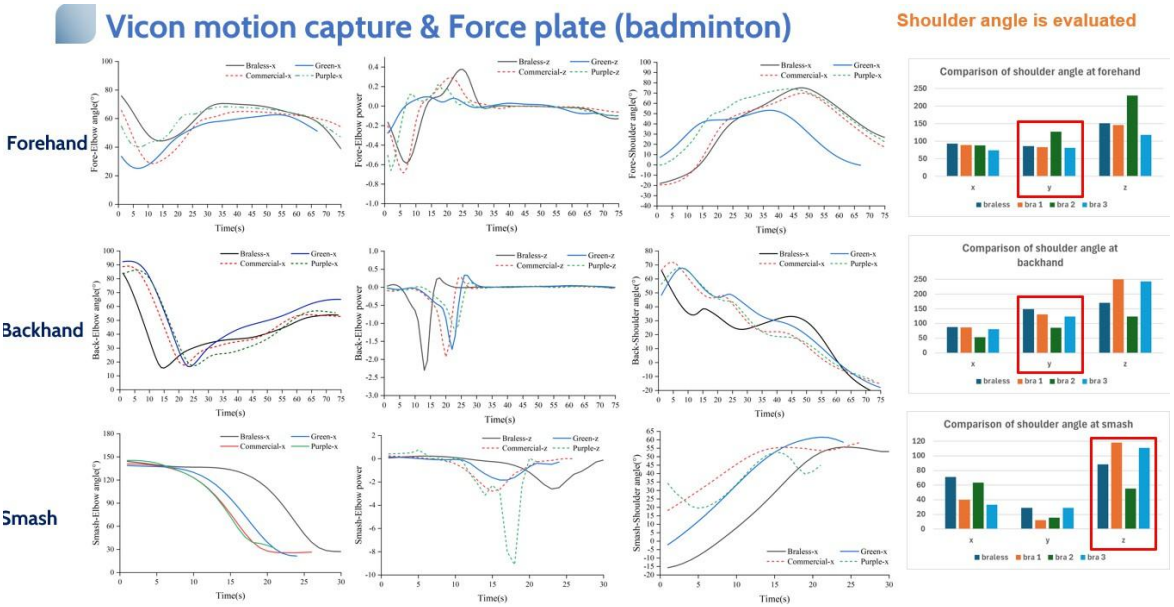


Figure 31 Results of biomechanical analysis during badminton games

3. Summary of Findings

An online survey revealed that most of the female athletes are unaware of their correct bra size and lack knowledge about bra sizing, leading to frequent fitting issues with sports bras. To address this, a workshop was conducted for 40 elite athletes, providing information on sports bras and helping them choose suitable styles and size. Feedback was overwhelmingly positive, with 100% finding the workshop helpful and 97.4% receiving valuable advice on sports bra selection.

Two sports bras were tailor-designed for elite athletes in racket sports teams to enhance upper body movement while providing support. The bras received positive feedback on design style and fabric use, with satisfactory ratings in areas like shoulder straps, underband, and overall comfort. Objective evaluations compared the bras' performance with commercial sports bra, focusing on shoulder and elbow angles and power in tennis and badminton. Results showed that the asymmetrical design features were crucial for improved performance, offering less restriction compared to commercial options.

4. References

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