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Sports Bra Design Based on Dynamic Elder Women Avatar ⋆

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Abstract

Elder women often suffer from chest pain and pressure discomfort due to breast displacement during exercise. To design functional sports bras that will mitigate chest pain and pressure discomfort under dynamic conditions, a survey was completed to find out the bra design special requirements and simulation experiments were carried out to investigate breast displacement rules. A standard sized running woman was selected as a subject to determine the typical breast movement positions, and an elder woman avatar was used to simulate the breast displacement. The results showed that by dividing the bra into different functional areas, the breast movement postures can be generated on the virtual model and this method could be applied to develop ergonomic sports bras that can limit the breast movement for elder females. Approaches involved in this research are also suitable to design sportswear with specific functional requirements for various age women.

Keywords: Sports bra; Breast displacement; Elder women; Avatar; Pattern; Apparel design

1 Introduction

Women, especially elder females, often suffer from bust pressure discomfort or pain caused by breast displacement during exercise. Senior women therefore often place factors related to sports bra functions such as fit well, comfort, deterring breast displacement (BD) at a higher priority for their breast care. By far there have been many studies focusing on bra issues in the general female population. Berger-Dumound [1] reported that the most effective breast motion-limiting bras were often uncomfortable while the bras with a high rating in comfort performed poorly in breast motion controlling. Jutel [2] suggested although the breast motion is restricted most effectively when a bra firmly held the breast tissue close to the body, there is a need for sufficient

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elasticity in the horizontal plane to allow the chest to expand during respiration. Hence, the functional performance of sports bras depends mainly on achieving a balance between reducing BD and improving pressure comfort in specific dynamic conditions [3]. However, only limited attention has been given in the scientific literature to the success or failure of various sports bra design features in reducing breast motion [4].

Typically, aging and menopause affect the anatomy of female breasts [5, 6]. The breasts and body shape of middle-aged women change when they start the menopause phase, and their Cooper's Ligaments elongate, resulting in flaccidity and breast sagging [7]. These changes in breast characteristics cause issues such as breast tightness, uncomfortable, or poor breast support when older females wear a commercial sports bra. It is difficult to find commercial sports bras meeting senior women's special requirements including breast protection, fit, and pressure comfort [8]. Issues such as inadequate breast support can affect wearer health, including low back pain and loss of posture, and even reduce their daily physical activities, etc. The paper aims to design a functional sports bra that will provide breast protection during sports activities. Typical breast movement positions are identified during running of elder women. The protective sports bra is designed by well-fitting on the elder female avatar to minimize BD. Fit simulation is also conducted to evaluate the functional sports bra design on an elder female avatar.

2 Methodology

2.1 Survey

A custom-designed 15-question, self-administered survey on sports bra usage was approved by RMIT University College Human Ethics Advisory Network (CHEAN A&B 22595-11/19). There were 26 participants from an outdoor activity group consisting of women aged 50 and over. The participant age groups are 50-55 years, 30%; 56-60 years, 43%; 61 years and over, 27%. Their bra size is classified into two categories: small [A–B Cup], 35%; large [C Cup +], 65%. The survey asked the participants to describe their level of satisfaction with regarding to sports bra design features and sports bra wearing issues.

2.2 Software

CLO 3D software from CLO Virtual Fashion Inc. was used to complete garment design and evaluation. It was applied not only to complete the sports bra prototype but also to evaluate the designed sports bra in line with a virtual fit assessment Richpeace CAD system from Tianjin Richpeace AI Co. Limited. Richpeace CAD system was mainly applied for two-dimensional (2D) pattern sports bra design. Through digital input or output between CLO 3D and Richpeace CAD system, 2D patterns were converted to a three-dimensional (3D) pattern, or vice versa.

2.3 Avatar

According to Burnett's report, sports bra usage among older women wearing a C+ cup size bra was below 41% due to breast pain caused by vigorous activities and poor breast support [9]. Thus, in this investigation, an elder avatar of C cup bust size was created. The measurement

items were based on the standard of GB/T 16160-1996 "Clothing Anthropometry Positions and Methods" [10]. As shown in Fig. 1, 9 measurement lines of the upper body were selected. The upper body size data was defined by referring to Aldrich's metric pattern cutting for women's wear [11]. Table 1 reveals a noticeable difference in measurement data between young female and elder woman of C cup bust size. The data of the breast height line (SNP to BP in Fig. 1) indicates the breast sagging among elder women. Fig. 2 shows the avatar created using the elder women upper body data in Table 1.

Table 1: Differences of upper body size between young women and old women (cm)

	Shoulder Width	Bust	Under Bust	Waist	BP to BP	SNP to BP
Young	37.5	82.5	67.7	62.3	16.4	26.7
Elder	39.9	102	89.5	85.1	18.9	28.7

Data source: Aldrich's metric pattern cutting for women's wear [11]

Note: SNP (Shoulder Neck Point); BP (Breast Point)

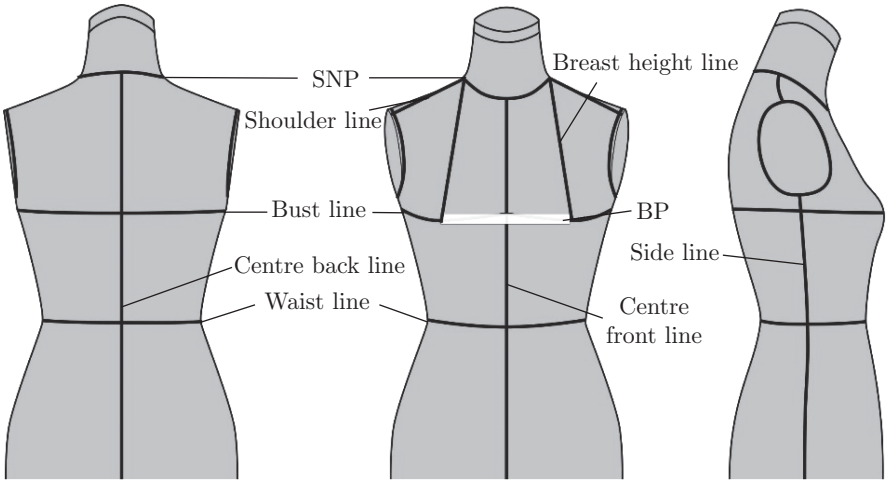


Fig. 1: Measuring items of upper body for avatar creation

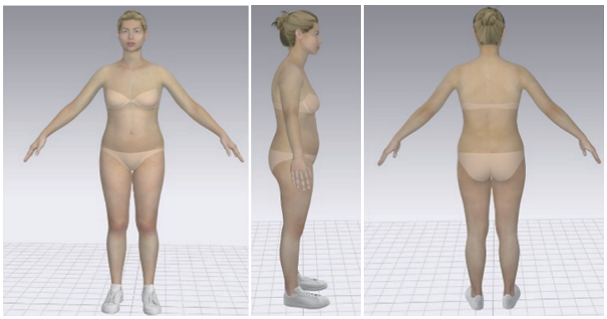


Fig. 2: Elder woman avatar of cup size C

2.4 Sports Bra Prototype Design

A sports bra can be designed based on the digitized avatar in line with body motion, individual needs, and body morphology [12, 13]. Sports bra prototype was created assuming that the aesthetic and sports bra construct value was acceptable [14] on the basis of breast morphology analysis. In other words, the prototype design was with attractive appearance and useful bra structure, including shaping the position of the breast and figuring bra to be appropriate body type. In this paper, functional sports bra was designed to reduce BD based on the protective sports bra prototype. The bra prototype structure can be achieved according to the breast morphology as described by the breast depth and circumference. As shown in Fig. 3, the black lines represent breast circumference at certain depth and the red lines indicate the breast depth profile. Chang [15] reported that the breast depth and breast circumference are variables to reflect the 3D breast and describe the size and fullness of the breast. Normally, a big breast circumference is corresponding to a relatively deeper depth of breast.

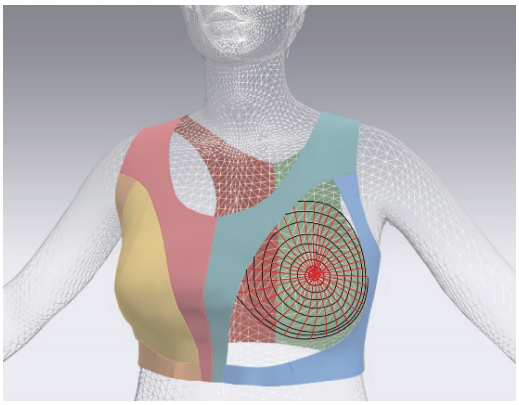


Fig. 3: Breast depth and breast circumference (the bra is on the transparent avatar)

The bra design features were chosen in terms of the type of physical activities required for elder women rather than commercial encapsulating bras. By referencing the data of Aldrich's metric pattern cutting for women's wear [11], the bra prototype structure can be created. Fig. 4 shows the protective sports bra prototyping created on the elder women avatar with the Richpeace CAD system and CLO 3D. Furthermore, 2D patterns can also be obtained by flattening the 3D sports bra, as shown in Fig. 4.

2.5 Sports Bra Prototype Construction Analysis

Fig. 5 shows that the bra prototype is designed to have a breast comfort zone and the pressure zone. The relatively comfort zone refers to the base part of breast with a large circumference. It has a low degree of breast displacement during exercise. The high-risk (pressure) zone is where the breast is overstretched during sports activities. In Fig. 5, Zone 1 and Zone 2 are the bra components forming the chest base parts. There is limited BD occurring in these areas during exercise. They are marked as the relatively comfort zones. Zone 3, the breast encapsulation area, is a high-risk zone due to breast overstretching. It is the essential area of bra to cater the elder women special requirements for BD control. Thus, a degree of pressure should be adopted in this area to deter intensive BD during exercise, i.e. Zone 3 is designed to be tight-fitting to some extent.

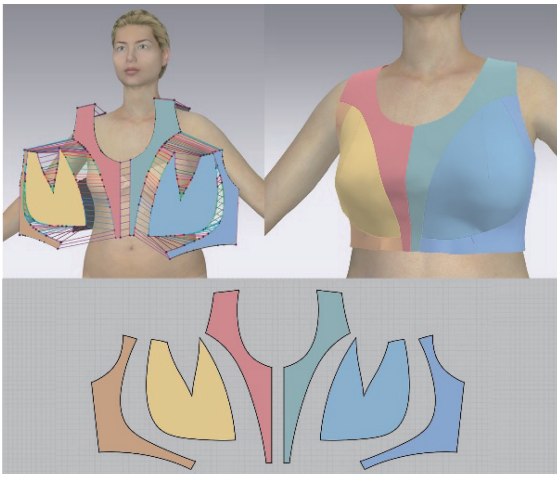


Fig. 4: Sports bra prototyping

Note: The colour presents different patterns of sports bra prototype. The 3D prototyping is created with CLO 3D software and the 2D patterns are created with Richpeace CAD system.

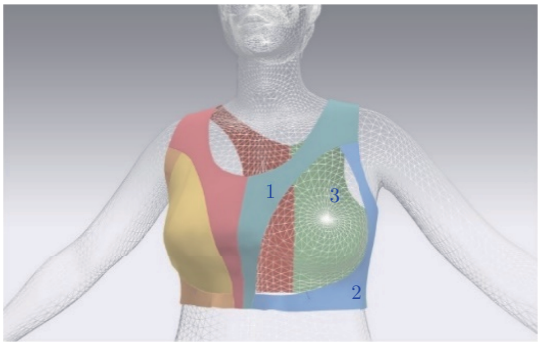


Fig. 5: Dividing functional area of bra on the transparent avatar

3 Results and Discussion

3.1 Survey Results

As shown in Table 2, the respondents to survey questions indicated that they disliked some features of their sports bra. The survey revealed that 69% of the respondents had exercise-related

Table 2: Summary of sports bra wearing issues (most important to least important)

Issue	roblem description
Support	A sports bar does not provide the support needed for high intensity exercise e.g. boxing and skipping. For better support, a bra with a tight crop top bra over the top is needed.
Pressure	Bras need to be tight to be supportive. But sometimes this is uncomfortable; too tight around chest. The bra cup size does not fit breasts.
Size	Decent priced and functioning sports bras are not always available in size.
Bra straps	Dig in; Need wide shoulder straps.
Fabric	Bulky; Unbreathable; Uncomfortable.
Donning and doffing	Difficult to take bra off. Need change rooms avoiding embarrassment.

breast issues, such as breast support, bra size, tightness, etc. The issues are more noticeable for those with a sports bra of C cup or larger. Niemczyk et. al. [16] surveyed 273 female police officers. They found that for women with larger breasts, commercial sports bras created problems when wearing body armour. Though sports bras are intended to support and shape the breasts, their functions are incompatible with the protective function of ballistic vests. Therefore, sports bras should be specially designed to meet the demand from different groups of people.

In the survey, participants were also asked to prioritize the sports bra features that govern the decision of purchasing a sports bra. As shown in Fig. 6, among many factors considered, the participants rated that the top priorities for sports bra performance are lowering BD, breast support, comfort, and fit well, etc. From Fig. 6, the key aspects of sports bra design are clear – minimising breast movement, enhancing breast support, fit and comfort. In addition, the bra should be designed having crop tops with wider straps to suit the avatar shape, as shown in Figures 3-5.

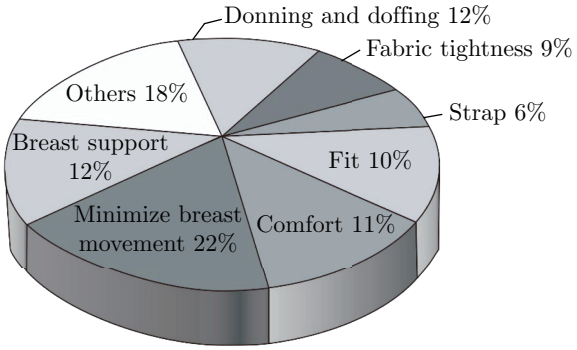


Fig. 6: Impact factors of purchasing a sports bra

3.2 Typical Dynamic Breast Positions

Motion features of body parts could be positioned on avatar from the actual body image data for virtual garment design [17]. For example, the breast motion features could be positioned based on her breast postures during running. Fig. 7 shows four typical breast movements of a runner. The dynamic range of the breasts while running can be determined with the reference of breast

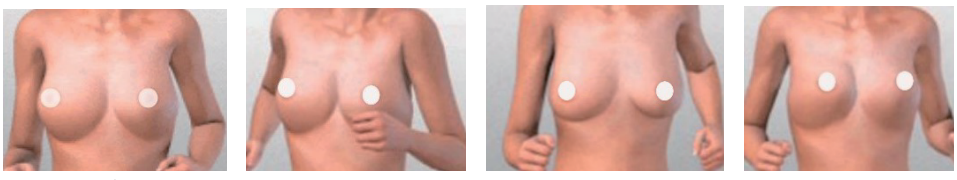


Fig. 7: Typical breast motion postures
(from https://www.google.com/imgres?imgurl=http%3A%2F%2Fwww.shockabsorber-us.com%2Fwp-content%2Fthemes%2Fshockabsorber%2Fbounceometer%2Fus%2Fimages%2Fshockabsorber%2Fanimations%2F2_1_face.gif%3Frdm%3D0.08148897485807538&imgrefurl=http%3A%2F%2Fwww.shockabsorber-us.com%2Fbounce-o-meter%2F&tbnid=Dvx2iBcskZf_zM&vet=10CA0QxiAoAWoXChMIiK3ZnPO46wIVAAAAAB0AAAAAEBk..i&docid=zc9yIziHDR2LdM&w=940&h=264&itg=1&q=breast%20posture%20running&ved=0CA0QxiAoAWoXChMIiK3ZnPO46wIVAAAAAB0AAAAAEBk)

profile in standing position. In Fig. 7, BD of image A is the leftmost position of breasts, BD of image B is the topmost position that the breasts can be stretched to, BD of image C is the farthest down position of breasts, and BD of image D is the rightmost position. The BP positions of the four typical postures are essential references for sports bra design.

3.3 Mapping Typical Breast Positions on Avatar

According to the survey results, reducing BD is a top requirement for a sports bra. Hence, the sports bra performance can be improved when taking BD into account during the bra designing phase. The sports bra design has to cope with the issue of additional breast stretching possibilities in specific pressure areas to accommodate the dynamic BD.

A dynamic analysis method was taken to study the breast movement posture of a virtual runner. The steps involved in static measurements of captured animated images, including (a) identifying running-related postures and motion sequences; (b) capturing each posture one step at a time, (c) measuring the body in movement poses [18]. This approach is adopted to map typical breast movement. In Fig. 8, the identified A, B, C, and D postures are the typical BD with blue mesh lines on the avatar. The BD is clearly shown through the convergence BP of the blue mesh lines. Also, these typical postures represent the maximum range of actual breast movements in which the runner's breast bore the most intensive pressure and stretch.

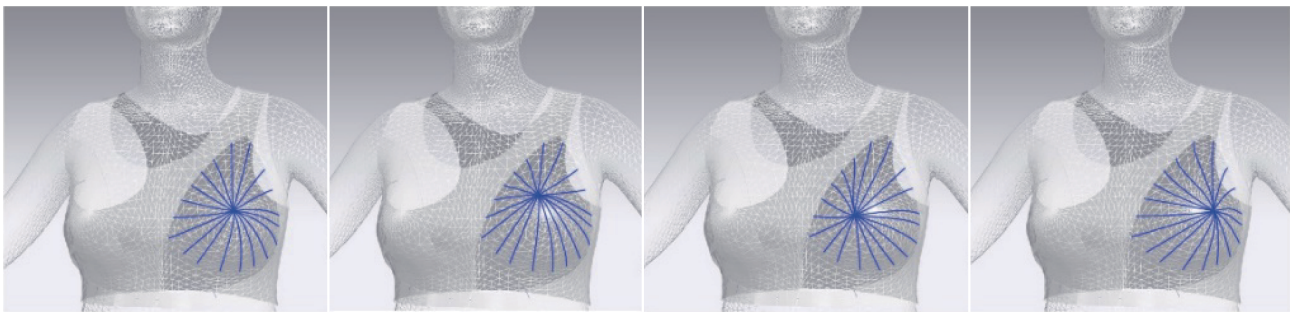


Fig. 8: Mapping typical postures on avatar

3.4 Dynamic Sports Bra Pattern in 2D

The structure design of sports bra could be carried out directly on the elder women avatar with BD postures. The essence of this method is that sports bra could be accurately designed according to the range of breast BD. It is complicated to understand what the typical breast movement postures are for the virtual runner. Patterns in 2D can be used to flatten a complex 3D structure. With the technique, the sports bra structure variation caused by the breast movement can also be observed through the 2D patterns in the four typical positions. Fig. 9 shows the 2D sports bra prototype patterns, where in Zone 3 BP refers to the static breast position. For the enlarged Zone 3, BP' indicates the stretched positions of breast. By comparing BP' with BP, the 2D patterns present the range of BD, which is the high value for sports bra design and reducing BD.

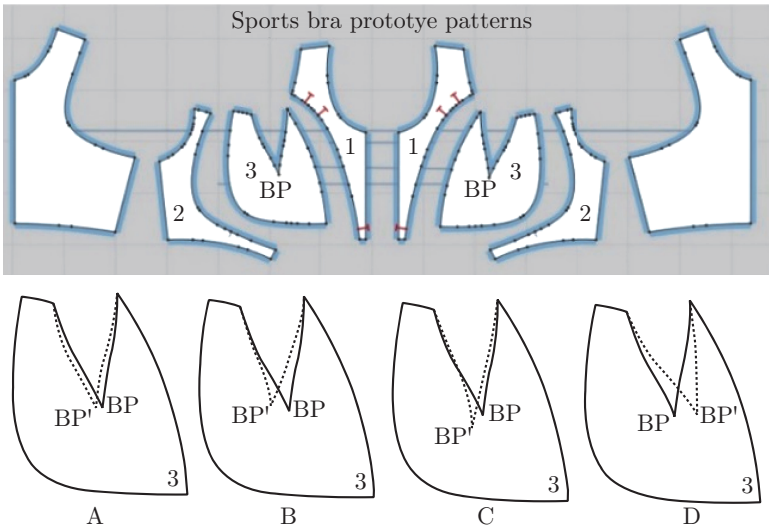


Fig. 9: Variation of BP in 2D patterns for typical breast motion postures

3.5 Comparison of 2D Patterns

The four typical postures, A, B, C and D, with the maximum BD can be shown by the deformational 2D patterns when the sports bra was designed based on dynamic avatar. These flattened patterns in Fig. 9 present large differences due to dynamic positions. Hence, it is necessary to take several steps to adjust the 2D patterns to accomplish and evaluate functional sports bra design:

(1) The four typical postures of 2D Zone 3 patterns vary greatly when their darts are merged. As shown in Fig. 10, Zone 3 is divided into three parts, a, b and c. It could narrow the degree of 2D pattern deformation by reducing the darts volume. It is convenient to observe and locate the displacement range of BP.

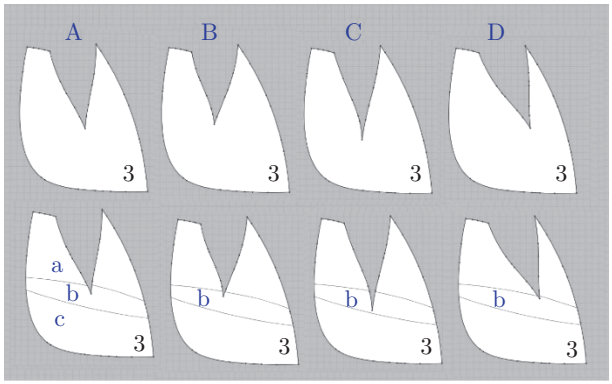


Fig. 10: Analysis of the dynamic range of BP

(2) In Fig. 11, protection Zone 3b patterns of four typical sports postures, A, B, C and D are extracted for adjustment, including the alignment and merge of darts, smooth structure lines. The conversion shows that Zone 3b patterns vary to a different degree.

(3) In Table 3, Zone 3b patterns are analysed and compared among the four-movement postures. The four Zone 3b 2D patterns show substantial differences in shape.

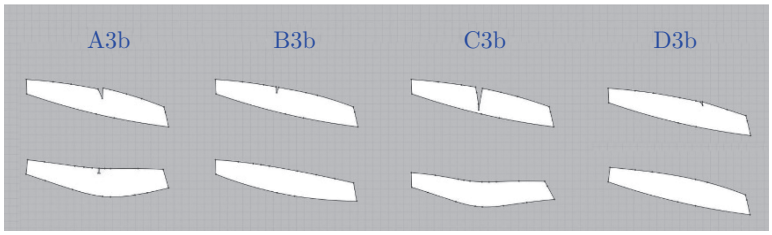
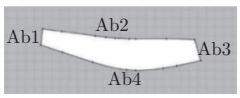
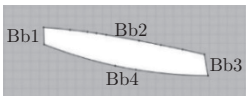
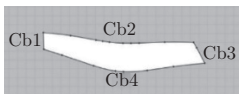
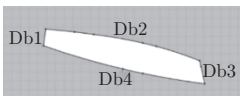


Fig. 11: Adjusting 2D patterns of Zone 3b areas (Top row: Zone 3b in Fig. 10; Bottom row: adjusted Zone 3b for reducing BD)

Table 3: Variation of size of Zone 3b areas between ABCD movement positions

Zone 3b								
Data	Ab1	Ab2	Ab3	Ab4	Bb1	Bb2	Bb3	Bb4
(cm)	1.88	17.75	2.5	19.13	1.89	18.27	2.39	18.81
Zone 3b								
Data	Cb1	Cb2	Cb3	Cb4	Db1	Db2	Db3	Db4
(cm)	1.89	17.47	2.68	19.04	1.88	18.08	2.65	19.01

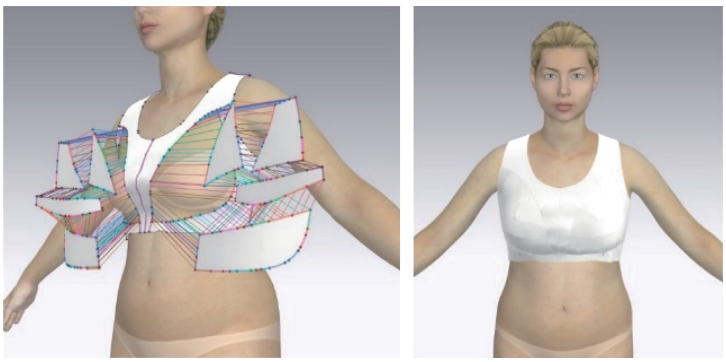


Fig. 12: Fit of sport bra on avatar

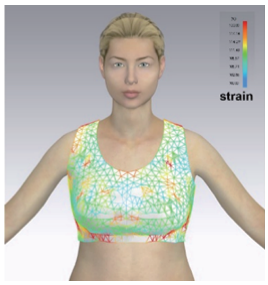
Based on Table 3 data, the adjustment is done by selecting the pattern closest to the average length to accommodate the BD in all directions. Take b2 lines for example, the average length is 17.86 cm, which is the closest to Ab2. Thus, the adjustment was done by selecting Ab2.

Fig. 12 shows virtual sewing the 2D patterns, i.e. the 2D sports bra patterns are transformed into 3D shape on the elder women avatar. As the patterns were created based on the avatar data, their 3D shape apparently fits the standing avatar.

3.6 Fit Virtual Evaluation

To ensure a precise dynamic fit for wearers, the term 'fit' should first be correctly understood. Live models and dress forms are common standards used to test clothing fit in trials and are judged by experienced specialists [19]. An avatar designed based on the elder women's body

Table 4: Fit simulation and analysis

Fit mapping	Strain mapping	Stress mapping
		
Red: fail to wear; Yellow: too tight.	Red120%, too tight; Orange to yellow: 110%-120%, slightly tight; Green100%, fit well.	Red: 100, too hard; Yellow to green: 50, too loose; Blue0, fit well.
There is no any red or yellow colour appearing on the sports bra, indicating a good fit.	Green is the main colour on the sports bra although there are yellow, orange, and red colours distributed in rare areas, which aims at preventing breast displacement.	There is no red, yellow nor green on the picture. It means that the clothes do not cause a sense of pressure.

measurements data can present body shape and features. Furthermore, it can also be morphed to simulate real bodies as they grow, age, and move. Hence, sports bras could be evaluated in terms of fit and comfort on the virtual human body.

The fit simulation was carried out on the elder women avatar. The assessment approach was to observe closely the extent of contact between the avatar and sports bra through contact point colour. Three aspects, fit, strain, and stress were evaluated. As shown in Table 3, the fit mapping is to evaluate whether the avatar is suitable for wearing this sports bra. Through the strain mapping, the deformation degree of the sports bra fabric can be observed. The stress mapping reflects the distribution of sports bra pressure. The assessment results show that the performance of sports bra is well-fit and slightly tight. This proves that the designed sports bra will provide adequate control of breast movement.

Though the simulation presented in this paper is a useful tool for sports bra and other intimate sports apparel design, this study has some limitations:

(1) The breast position is an approximate location. Differences between the breast shapes, sizes and positions among elder women could affect the bra protection function. Different breast scenarios should be further simulated;

(2) Typical breast postures are extracted from a runner while the activity features differ from person to person; hence, actives that could lead to even larger breast displacement should be considered as well; and

(3) The fabric characteristics, such as stretchability and structure, as well as breast firmness contribute to the impact on breast pressure and further studies considering different fabric materials as well as breast softness and skin elasticity are warranted.

4 Conclusion

The sports bra features are highlighted through a survey to elder women. The survey participants feel that a sports bra has poorly breast support, provides inadequately control breast displacement, and it is uncomfortable, or too tight during physical activities. To address the sports bra problems identified by the survey, sports bra design for elder women was carried out using an avatar and dynamic modelling technique. In this study, a new and efficient digital approach was employed to develop sports bras by analysing breast dimension changes in specific dynamic positions. The computational technology offered advantages, such as fast in adjusting patterns on the elder female virtual model. The primary advantages included the possibility of designing sports bra by mapping breast displacement on the avatar, the application of shape flattening method for the transformation of the irregular 3D surface into the 2D patterns, and selection of appropriate patterns from the four typical breast postures. The virtual fit analysis was also conducted to evaluate the final sports bra. Based on the analysis of breast movement positions, the sports bra designed can accommodated the breast dimensional changes from different sports activities. The developed method can also be used for functional garments design for women with special requirements for caring their breasts.

Acknowledgement

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