Conference Paper

Qualitative Observations on the Design of Sports Bras for Wear under Body Armour

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Abstract

This paper presents the results of preliminary research designed to explore in depth the design, fit and comfort of selected sports bras for large breasted women worn under soft body armour. Female armed personnel need to feel safe and protected in soft armour vests, giving them physiological comfort to perform their duties daily. Troublesome physical and additional physiological problems in relation to the female body are frequently caused due to the poor design of various bra components. Different breast sizes require unique bras designs. Specifically, when it comes to plus-size breasts, all the difficulties of fitting are more evident. In general, retail bra designs are not overcoming the above-mentioned bra's wear problems even before consideration of how they relate to be worn under the soft body armour.

As breast size and shape vary greatly between individuals, the design of bra size and style are important. In addition, fit and comfort are the most important factors of concern to the customers. With an aim to achieve a perfect bra shape, fit and comfort, designers have a strong drive to develop a superior quality bra by properly using components and materials with high performance.

Five commercial sports bras were selected based on their suitability for wear under body armour. The bras were fitted on a fit model and ranked in terms of the design criteria (1) non-wire, firmness and comfort, (2) fit and size range (D to G-cup) shape, (3) moisture wicking, and (4) composition and textile quality. They were then assessed for correct fit by an expert bra fitter and photographed to assess frontal and side-shape protrusion for mobility and for comfort on the side upper arm. Comparisons indicated differences in the side arm protrusion for some popular brands. Further wear test under a simulation mock-up body armour vest was conducted for observing comfort and moisture management performance over a period of 6 hours. The bra comfort performance was compared.

Keywords: Plus-size bra, Intimate apparel design, Fitting, Comfort

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1. Introduction

The performance of military personnel and police officers can be significantly affected by the level of comfort, both physical and psychological, experienced while wearing body armour vests. For female officers, the body armour vests were not designed to fit their bust shape. The compression of the breasts under the vests can have a considerable negative effect on physical and psychological comfort and on job performance [2, 7, 21–23]. There are many females who find their vests very uncomfortable

and choose to wear them for only a limited time due to this discomfort [8]. Thus, an examination of the effect of body armour vests on the performance of female officers in the police force and the military is both necessary and overdue.

Advanced body armour technologies aim to reduce vest weight in order to enhance comfort [9]. Although an individual may be body scanned for fit, a different bra can change the bust shape of the soft body it encapsulates and therefore add to discomfort in fit. The interaction between the protective vest and the body is thus a very important aspect to consider in the design of protective body armour, particularly for women requiring a large cup size bra.

The cup is a fundamental component of the brassiere and is normally supported by an underwire. However, the wires themselves could be a hazard. The wires in a bra could become a projectile component when stabbed or shot at. Non-wire soft cup bras, such as sports bras are comfortable, and hence are becoming popular [13]. Hence, this study explored and compared some popular non-wired sports bras for design, shape, comfort, fit and moisture wicking qualities for the D-cup and larger. The bras included in this study were selected based on the following criteria: (1) non-wire, firmness and comfort, (2) fit and size range (D to G-cup) shape, (3) moisture wicking, and (4) composition and textile quality. A perfectly designed bra is supportive, has no projectile components, and is compatible with a given ballistic vest (i.e. shaping the bust to prevent gaping of the vest on the side of the arm without causing mobility issues of the arm). In addition, the moisture wicking qualities must be suitable over a period of 6 hours under a ballistic vest, so that body moisture and sweat will be dispersed, spread or moved through the bra.

A sports bra is a woman's undergarment designed for extra support, minimising breast movement and providing protection during recreational activities. It is sturdier than a fashion bra and is designed to reduce potential damage to chest ligaments. Research has shown that there are no significant differences in comfort ratings between a correctly fitted sports bra and a fashion bra [3]. A survey of Australian women has also found that women frequently falsely perceive the tightness of sports bras as possibly impeding their respiratory function and, in turn, their exercise performance [4].

The quantification of breast comfort has been examined and reported [24]. Previous research investigating breast comfort during activity has utilised a 10-point numerical analogue scale with start, end and midpoint descriptors in order to obtain a subjective rating of comfort (Mason et al., 1999); [24].

Research conducted in the UK suggests that there is a lack of available data on bust circumference. Thus, in terms of 'plus-size', it is unclear what size determines a plus-size bra [10]. Despite this, a "full size bra" is generally considered a "D" cup, so most brands specializing in plus-size bras, consider the size to be "32 D" [10]. The size "32" refers to dress size and the "D" refers to the bra cup size. Some brands specializing to this target market include Empreinte, Curvy Kate, Freya, Panache, and Elomi.

As breast size and shape vary greatly between individuals, the perfect design of bra, in terms of both size and style, is very important. In addition to this, [5] states that the poor design of bra components frequently cause physical and physiological problems

to the female body. This may include wire digging into the skin, irritation from the bra fabric, and tight shoulder straps. The greatest difficulties that women face in bra purchases are in finding a perfectly-fitting bra that is both comfortable and moulding the body to a desirable silhouette [12].

Women generally do not know their true breast shape and size [11, 16, 18]. As a result of this, incorrect bra size may cause muscular and nerve problems [25]. Problematic bra fitting substantially increases in larger breasted women [11]. Indeed, incorrectly fitted plus-size bras can be the cause of numerous health problems related to the arms, neck, back and head. Such issues can include exercise-induced breast discomfort [15], which, if serious, may result in the wearer being advised to undergo breast reduction surgery [17]. Further studies have also found that, in contrast, if a bra is correctly fitted, up to 85% of these symptoms can be alleviated [16].

It has been reported that none of the traditional bra fitting methods are 100% effective [24]. When females adhere to standard bra-sizing measurement instructions to select a bra they most likely will not improve their bra fit. The measurements purport to be an estimated guess of the correct breast size [16, 19]. Furthermore the results suggest, as also from previous research [16, 18], that the Australian standard guidelines for determining bra size need to be reviewed, particularly as one of test bras was designed by an Australian manufacturer for Australian women. In view of these study outcomes, this research relied on professional fitting – a professional bra fitter was used to physically assess bra fit for the fit model and the wear tester.

Female armed personnel with plus-size breasts and in soft armour vests specially need the correct bra to maintain physiological comfort so that they will effectively perform their duties daily. Incorrect bras designs would also cause side-shape protrusion, affecting their mobility. In general, retail bra designs did not consider the problems of bras worn under the soft body armour.

This paper reports a preliminary study that explores and evaluates existing commercial sports bras in cup sizes D and above, in order to formulate detailed design criteria for a bra prototype to be developed for wearing protective body armour. Five commercially-available non-wired sports bras with different fibre contents and design features were chosen for this work because of the type of physical activities required for women in the police and military forces including running, walking and jumping. This study focused on the evaluation of the functional performance of the bras in terms of comfort, shape and material wicking qualities. The aesthetic and vertical breast displacement values were assumed to be acceptable. Design investigation and wear test analysis were also conducted.

The aim of this study was to explore the range of commercially-available plus-size bras. This was done in order to find either a bra that meets the design criteria proposed in this paper, or a bra that contains the majority of desired design features. This will assist in developing a new prototype bra designed to assist in optimizing the interrelationship between the bra wearer, the bra, and the protective vest. This study was designed with the bra wearer in mind. It aimed to improve body armour fit through appropriate bra design, improving under-garment fit to optimize outer-garment fit. Two main issues/variables that drove this research were:

1. Minimized upper arm mobility caused by soft-cup protrusions.

2. Overheating caused by inappropriate materials and design, which did not take account of heat caused by wearing protective body armour over extended periods.

2. Methodology

The study focused on the evaluation of the functional performance of the five different bras in terms of comfort, shape and wicking qualities. The aesthetic and vertical breast displacement values were assumed to be acceptable. Five different extreme-control sports bras were examined, consisting of one compression bra and four encapsulation bras. The bras were selected as representative of the different features of non-wired sports bras currently commercially available. The bra samples were manufactured under the brand names Shock Absorber™ (DBApparel, UK), Anita Extreme, Anita Momentum, Freya active wire-free and Panache wire-free.

Two human subjects took part in this study. A plus size cup human model, size 10 G, was for the images that show the side bust protrusion in non-wired bras since size 10 G seems to be the best seller for Brava. Examination of the custom bras and interviews with expert sports bra fitters were conducted. This methodology eliminates any potential errors due to the lack of standardization of bra sizes amongst different manufacturers and different bra styles. The bras were professionally fitted on the subject and then photographed as a means to investigate bust protrusion on the side of the bust. The bras were also examined in terms of function, comfort, moisture wicking and shape. The bra fitter had been trained and had worked in a store for 8 years specialising in D-cup and above fittings. The most appropriate bra size was provided for both subjects to try on. The fitting procedure follows a standard process. Firstly, the correct tensions of the under band and the shoulder straps were ensured. This is a subjective method. Secondly, the subject leaned forward so that her breasts completely filled the cup to ensure that there was no gap, bulging, wrinkle, digging or sliding. Lastly, she raised her hands to check that the bra stayed in place. The bra fit was then assessed and ensured by the same bra fitter, according to a professional bra fitting checklist table. The validity of professional bra fitting service has previously been established [6].

The second participant (the researcher) tested the 5 bras. The subject wore a test bra, a polyamide singlet and soft body armour vest. The wear test was based on a previous study on multiple response measures while studying one specific garment property. The objective of this approach is to determine the effect of a garment variable on multiple performance measures. A multiple performance/single property approach is appropriate when comparing similar garments which substantially differ in only one property and which will be worn when performing complex tasks, e.g. comparing different designs of bras that are in the same size and using the same materials. Variables of interest in this example might include range-of-motion, movement time and comfort [1].

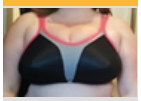
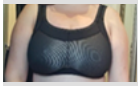
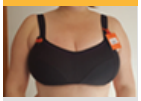
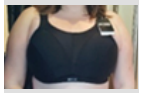
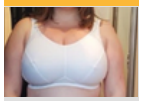
Freya non-wire Active	Anita Momentum	Panache wire free	Shock absorber	Anita Extreme
				

Table 1: Bra fitting on a human model.

The wear tests used the 10-point numerical analogue scale to assess for overall comfort focusing on wicking qualities, mobility – ease of arm movements (shape of bra), and bra stay in place over a period of 6 hours, which is an approximate time of a shift for police officers. A Likert scale was used to record data every hour. Activities was done over 5-week period and included activities in the gym, driving, and daily tasks like shopping, office work while wearing a body armour vest. This approach determined the effect of one garment on multiple performance measures and was appropriate when comparing similar garments which will be worn during performing complex tasks.

3. Results and Discussion

The five bras, meeting most of the design criteria proposed, were professionally fitted on a human model for photographs as shown in Table 1 to investigate bust protrusion at upper arm. Additionally, a mock up ballistic vest was made up (15 layers of nylon sheeting) and worn over the bras to test the wicking and comfort of the bras over a period of 6 hours. The bras were also tested over a period of six weeks to examine their function, comfort, and moisture wicking performance. This was one test per bra using one individual subject. The wear trial results are summarized in Table 2.

A comfortable bra should provide good extensibility without excessive tension (around the upper torso) to allow body expansion during breathing and/or after meals [14]. A good fitting bra should provide adequate support to the breasts through the shoulder straps, underband (also known as the base of the bra), wires and two cups [20]. It should have an adequate 3D structure and proper stretch to fit the body contours. The underband part of the bra should be designed and built to withstand 80-85% of the breast weight [15]. All five bras were wear-tested under the same conditions, and the following seven separate qualities of comfort were observed.

1. *Bra stays in place, bust stay in place* (separation): The Freya Active was the only bra that separated the breasts (good quality as it gives a dry comfortable feeling in bust centre). The four other bras had separate cups, but the breasts did not stay separated after exercise. The bust "migrated toward each other" and got "crushed". There was no gap between breasts and they got sweaty and over-heated. In addition, excessive heat and moisture build up between the breasts causes heat rash. Freya Active prevented this due to good separation.

2. *Shoulder straps*: Shoulder straps of all bras remained in place (these were good quality, since no adjustment was needed for slipping off-shoulders). The only

Bra	Positive	Negative
Freya non-wire Active	• Sizes A-GG • Breast still dry after 2 hours intensive walking, running • Smaller sizes possibilities • Straps are very comfortable • Gives great separation and coolness to centre front	• Spilling on side • Seams on inside irritating • Sweat running down from under bust • Trapping moisture causing heat rash build up • Discomfort around shoulders • Elastic band wet • Gives bust a weird shape • Seams on inside not comfortable • Loose panel • Breathable "V" shaped panel between the cups kept the bust dry for up to 3 hours however it did not dry when aired and bra became very uncomfortable • Bra remained wet even after opening vest for air, the bust centre heat build-up became unbearable • Shape interfere with arm movement when in mock up armour vest
Anita Momentum	• Size A-H 30-46 • Cups Seamlessly shaped cup, Straps wide semi elastic support straps padded throughout and adjustable support • Bra and breast remained dry after 3 hours became damp. Underbust and centre bust started with moist build up. Underbust band got damp but seem to dry when aired • Bra stayed in place, very comfortable throughout	• Shape protrudes to side • Bulges at underarm • Uncomfortable at underarm/ shaping wrong when in mock up armour vest
Panache wire free	• Very comfortable fit. Racer back option does not bring bust in on the side. Created a fuller rounded shape	• Bra feels very hot after an hour • Arm at inside/very uncomfortable • Bust got wet and stayed wet after an hour • Bra stayed damp throughout test period • Centre bust very hot. Underband curled up, very uncomfortable • Shaping not good • Very hot!

Table 2: Summary of the positive and negative observations of the 5 bras observed and tested.

Shock absorber	• Size range • It brings the side of the bust right in. • Bust fit well in cups/good separation. • The bra is made out of elastic material, which functions to compress both breasts on the chest wall without separation • Open band in the back for airflow and if you need to make the top or bottom tighter or looser • The internal "slings" give your breasts a place to sit, without overly compressing them	• The Compression Bra flattens and widen the bust. It became very uncomfortable after 1-2 hours/Itching/compression feeling. It trapped the moisture under the bust and bra remained wet • Pressing the tissue down in a compression bra makes you look wider • The bra became more comfortable after wearing it for half an hour but over the period of 6 hours' headache/back discomfort. Straps became very tight and caused headache and neck muscle spasm. Cup discomfort became unbearable after two hours • Flat rounded shape • Shoulders ache/ headache
Anita Sport	Size range - Material and Design: • Wicking meets design criteria in terms of heat control/comfort/aesthetics • No shoulder digging • Very comfortable for long periods of wearing • Bra and breast remained dry-even though perspiration dripped from face, neck and shoulders • Area not covered by bra: perspiration • Started wearing a tank top (keeping dry around bust area), but waist felt damp, fabric appeared damp, tank top dried with minutes when vest sides opened • Areas that were not covered remained wet from perspiration • Cup fits excellent/bust doesn't feel constricted • Comfort level of bra scale 1-10 =10 • Straps Ergonomically-styled support straps, padded throughout • Back wing, breathable mesh. Very dry and comfortable	• Smaller back sizes, straps at the back - position might be too close to shoulders/observed on smaller back • Widening of the shoulder straps need to be higher on shoulder bone • Rounded shape/fitting comfortable throughout

Table 2: Summary of the positive and negative observations of the 5 bras observed and tested.

limitation is that it was tested on a single subject with a broad back with non-sloping shoulders.

3. *Underband*: The underband of Freya, Anita Extreme and Anita Momentum remained flat and in place and comfortable (therefore good quality since the underband is the "spine" of the bra and needs stability during movements); however, Panache rolled up after an hour and remained very uncomfortable (undesirable quality).
4. *Back-wing band*: Back-wing (bra sides back) of Anita Extreme and Anita Momentum was most comfortable due to the extended stretch factors and the wicking quality of the fabrics. This is a good quality since the other bras were not comfortable due to dampness and heat which is not desirable for extended wear.
5. *Wicking cups*: All bras were very comfortable in the first hour. However, as the body heated up with exercise, the underbust and centre-front bust became very hot and damp, and remained damp with sweat even after slowing down. All five bras were damp (next to skin and outside cup) when removed after 6-hour exercise.
6. *Wicking qualities of underband*: Panache Wire-Free underband felt extremely hot and damp and remained damp and uncomfortable after 50 minutes of wear. This is not a favourable quality for this use. The underband on Freya and Shock Absorbers became damp and stayed damp after 1-2 hours (slightly better than the Panache Wire-Free but it was very uncomfortable throughout the wear period. Anita Momentum and Anita Extreme remained dry for the longest period; however, the wearer also felt damp on skin after 6 hours.
7. *Shape and mobility of bust next to the upper side arm*: Panache, Freya and Anita Momentum were felt more uncomfortable than Shock Absorber or Anita Extreme, due to the arms being restricted by breast side protrusion.

There are a number of limitations to this study, which must be acknowledged:

1. Only one participant undertook the six-hour wear-test on each bra, only one human model was photographed for the shape comparison and only five bras were selected for wear-testing. An increase in sample size will results in more reliable information.
2. The gym temperature remained consistent (22°C). Different environment temperatures may alter the results observed; however, the wear test conditions were indoors and outdoors.
3. Wicking-testing was limited and requires further study using lab-based objective measurements.
4. The side bust protrusion will need further investigation with quantitative scientific measurements.
5. The wear trial was carried out with mock up body armour vest. Hence, some observations may not be applicable to the bras without the vest.

4. Conclusion

The police and armed forces are placing more and more consideration on the fit and comfort of body armour worn by the frontline officers on a daily basis. Indeed, previous research indicates that there are fit and comfort problems for female undergarments with wearing body armour. This preliminary study evaluated the bras specific design criteria with the aim of assisting the comfort, fit and mobility under body armour vest for large breasted females. The wire free bras were selected specific to the target market. Attention was given not only to the bra fit but also whether the bra stays in place over a prolonged period, whether the shoulder straps slip off the shoulders easily, the level of support and the underband provide the necessary structure to the bra fit. Additionally, the moisture wicking of the bras was assessed for comfort, particularly the underband, since excessive heat is generated underbust.

Existing commercial bras are not specifically designed to be worn under non-breathable fabrics such as aramid vest for extended periods. The findings of the wear test included side bust protrusion, heat rash, and ill fit. They all contribute to the discomfort from the body armour. The Anita Extreme and Anita Momentum wicking qualities were significant to the rest. The design shaping of the Anita Extreme for side bust protrusion shaping was superior to the rest of the bras.

The study focused on the interrelationship of bras (bust sizes D-cup) and the soft body armour and the aim is to develop a new bra that may contribute to better fit of soft body armour as well as improved comfort for the wearers. This paper provides useful information for this effort. Further studies will focus on scientifically measuring the bust upper arm side protrusion, wicking tests, as well as thermal comfort of the selected bras on a sweating manikin.

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