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Assessment of Commercial Off the Shelf (COTS) Sports Brassieres for the U.S. Army Tactical Brassiere (ATB) Program

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ABSTRACT

The current paper summarizes selected results from the first phase of the ATB program, three-phase study to investigate, design and develop a brassiere appropriate for tactical duties for female Soldiers. Two specific research aims for the current paper are to investigate trends in commercial brassiere design features and understand how they linked with comfort/discomfort, interference and support, and to objectively describe those design features. Different brassiere designs had an effect on all compared metrics. Each configuration showed distinctive anthropometric characteristics, and those differences were linked with mobility metrics.

Keywords: Army tactical brassiere (ATB), Military anthropometry, Brassiere sizing, Sports brassiere, 3D scan, Human factors, Mobility

INTRODUCTION

In an effort to develop an Army Tactical Brassiere (ATB), a three-phase study was designed and executed. As the first phase, commercial-off-the-shelf (COTS) sports brassieres were assessed to investigate the effects of different design features on fit, mobility, and comfort. Based on the results from the first phase of the study, along with a systematic review of brassiere sizing development methodologies, an ATB sizing system will be developed in the second phase. In the third phase, for each developed ATB size, a fit model will be selected and an accommodation envelope will be constructed to develop the brassiere pattern as the last phase.

The current paper summarizes a part of the results from the first phase where the overall purpose was to document the relationship between the design features, the anthropometric characteristics, and their pros and cons as they relate to Soldier mobility. During the design feature assessment, anthropometric measurements as well as subjective ratings on brassiere support, comfort/discomfort and interference during the mobility assessments were analyzed. Specific research questions for this paper are two-fold, 1) was there

Table 1. Test item configuration.

Baseline (A) & COTS (B-G)		Cup Design		
		Hybrid	*Compression*	*Encapsulation*
	Straight	B	D	F
Strap Design	*Racer/Cross Back*	C	A, E	G

a clear trend in brassiere design linked with discomfort, interference and support? 2) if so, is it possible to objectively describe those design features in that configuration?

METHOD

Test Item

Prior to selecting the test items, results from previous relevant studies on sport brassieres were reviewed. Measurement of breast movement reduction is often used as a critical index to represent breast support (Zhou et al. 2013, Scurr et al. 2011). This measure of breast movement reduction was compared relative to brassiere design features, such as cup design (Scurr et al. 2011), strap configuration (Zhou et al. 2013, Bowles and Steele, 2013, Coltman et al. 2015, Page and Steele 1999, Yu and Zhou, 2016), cup padding (Zhou et al. 2013, Page and Steele, 1999, Yu and Zhou, 2016), and cup underwire (Zhou et al. 2013, Page and Steele, 1999), etc.

Among identified design features, this study selected two primary features, cup design and strap type, because they are the two basic design characteristics relative to other sub-details such as cup padding or cup with underwire. The number of different types of cup and strap design was limited to three cup designs and two strap types. This total was designed to limit the data collection duration to approximately 4 hours to avoid need for a meal break in the middle of the assessment.

In all, seven configurations (six COTS brassieres and U.S. Army standard issue brassiere as a baseline) were selected for assessment and comparison. The six COTS configurations were a combination of three brassiere cup designs (compression, encapsulation and hybrid (more than 1 configuration of cup design))[1] and two strap designs (straight or parallel straps (I I) and racer back or cross straps (X)). The configuration matrix is represented in Table 1.

Brassiere Fitting Process

Traditionally, in the United States, a brassiere size has two components, bra cup and band size, which are combined into the commercial brassiere size (e.g., 36C). Cup sizes are usually marked alphabetically with cup A having the smallest breast volume (i.e., A, B, C, etc.) while the band size is numbered in inches (i.e., 32, 34, 36, etc.). One unique feature in brassiere sizing is that the cup size interacts with band size. In other words, breast volume, denoted

[1]Pictures of selected COTS sport brassieres are not included to withheld the brand identity

Table 2. Measured anthropometric dimensions (mm).

Dimensions	Direct Measurements	Derived Measurements
Breadths	Thelion to Thelion[1]	
Circumferences	Chest[2], Underbust[1], Chest at Scye[1], Waist at Omphalion[2]	Circumference difference (Chest-Underbust, Chest at scye-Underbust)
Depths	Chest[2], Underbust[3]	Depth difference (Chest-Underbust)
Heights	Stature[2], Suprasternale[2], Axilla[2], Chest[2], Underbust[3], Omphalion[2]	Height difference (Chest-Underbust)
Lengths	Interscye I[2], Strap[1], Waist Front[1, 2], Waist Back[2], Chest cross[3], Side Neck to Axilla level, R & L[3], Axilla level to breast bottom, R& L[3]	Waist Front Length difference (ANSUR I-ANSUR II), Side Neck to breast bottom, R&L
Weight	Body weight	

[1]ANSUR I, [2]ANSUR II, [3]Developed for this study

by the same alphabetic character, is different relative to the band size, and increases (or decreases) as the band size increases (or decreases). For example, the breast volume accommodated by size 34C is greater than that by 32C.

Therefore, if predicted brassiere size is 34B, but the cup should be bigger or smaller, then adjacent sizes, such as 34C or 34A, should be tried. However, if the band should be longer or shorter than 34B with the same cup size, the trial size should be 36A to get a longer band with the same cup volume or 32C for a shorter band with the same cup volume. Sizes that share the identical cup volume (i.e., 34B with 36A and 32C) are called sister sizes.

Fitting trials for this study were all performed by Army clothing designers from DEVCOM Soldier Center, Design, Pattern, and Prototype Team (DPPT) and they started with the predicted size of each configuration. Following the predicted size, all needed adjacent and sister sizes were tried to identify the best-fit size brassiere for each configuration for each individual. This process was repeated for all test configurations.

Metrics: Anthropometric Dimensions

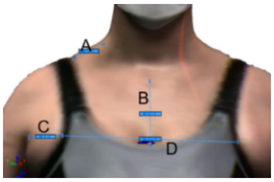
To capture the anthropometric characteristics, a total of 24 traditional dimensions were measured following the methodology established for ANSUR I (Gordon et al. 1989) or ANSUR II (Hotzman et al. 2011) where applicable. Additionally, seven derived dimensions were computed from the traditional directly measured dimensions. Table 2 details the measurements. Four additional dimensions were extracted from three-dimensional (3D) scan images captured by a Cyberware 3D whole-body scanner (see Table 3).

Metrics: Mobility Assessment (Subjective Rating)

Exercises for the mobility measurements were selected based on two primary criteria: high impact on breast movement and producing a low amount of

Table 3. Scan extracted dimensions (mm).

Scan Extracted Dimensions (Point-to-Point Distance)
A. Shoulder Exposure: Side neck point, right, to inner edge of the strap on the right shoulder
B. Center Neck Drop: Suprasternale to the highest point of the brassiere on the center front line
C. Exposure at Scye, R: Scye point, right, to the edge of brassiere on the right side at Scye level, parallel to the floor.
D. Chest coverage at Scye: between the edge of brassiere on the right and left side at Scye level, parallel to the floor.



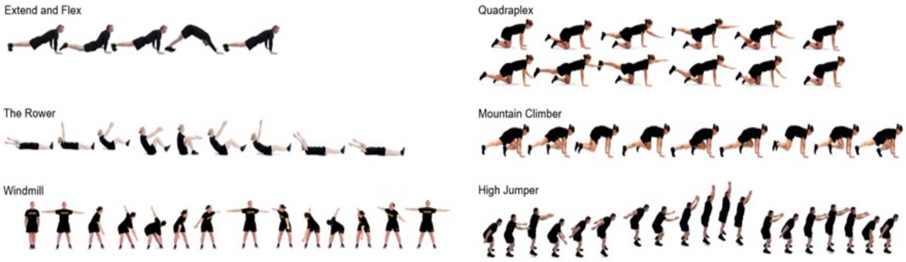


Figure 1: Selected six motions for the mobility assessment.

aerosol (due to Covid-19 safety precautions). The "Army pocket physical training guide" (U.S. Army, 2011) was the main reference from which all the exercise movements were selected so that Test Participants (TPs) could evaluate the brassiere performance based on common activities for female Soldiers.

A total of six exercise movements were selected that included: two low impact activities, Extend and Flex and The Rower; two medium impact exercises, Windmill and Quadraplex; and two high impact exercises, Mountain Climber, and the High Jumper. Sequential pictures for those six activities are represented in Figure. 1. Except for "Extend and Flex" and "Quadraplex", all exercise movements were repeated three times. TPs were told to perform "Extend and Flex" at their own pace, and to pause for 10 seconds per side for "Quadraplex".

Upon completion of each mobility task for each test configuration, TPs subjectively rated (on a 5-point Likert scale) brassiere support, discomfort and interference. At the end of the mobility session, TPs provided overall ratings on the attributes of the test configuration. Once data collection on all seven configurations were completed, TPs ranked all test configurations, including their own personally preferred sport brassiere.

Table 4. Descriptive body size/shape statistics for TPs.

Unit: mm, kg	All TPs (n = 19)		ANSUR II Female (N = 1986)	
	Mean	S.D.	Mean	S.D.
Stature	1613	80	1629	64
Weight	69.48	12.8	67.76	10.98
Chest Circumference	958	78	947	83
Waist Circumference at Omphalion	894	112	861	100

Analysis

Descriptive statistics, as well as frequency tables, were produced to compare subjective ratings on mobility tasks between configurations. A one-way repeated measures ANOVA along with Scheffé tests was performed on all applicable anthropometric dimensions (α<.05).

RESULTS AND DISCUSSION

Test Participants (TPs)

A total of 19 female TPs, 6 combat experienced personnel (5 active duty Soldiers & one veteran) and 13 civilian volunteers participated in the study. Ages ranged between 27 and 62 years old ($M = 38.84$, $SD = 8.82$). Personal information such as MOS and deployment history is withheld to maintain TP anonymity. Two (10.5%) TPs classified their race as Asian, one (5.3%) TP classified herself as Hispanic, two (10.5%) TPs did not answer, and the rest (n = 14, 73.7%) TPs classified themselves as White.

Test participants' body size distributions were compared to the Anthropometric Survey of US Army Personnel data (Gordon et al. 2014). Summary descriptive statistics for TPs are provided in Table 4. The distribution of study sample relative to ANSUR II population with a 98% ellipse (1^{st} to 99^{th} percentiles), 96% ellipse (2^{nd} to 98^{th} percentiles) as well as a conventional 90% ellipse (5^{th} to 95^{th} percentiles) is represented in Figure 2.

The study sample was shorter, heavier and broader at Waist Circumference relative to the ANSUR II parameters. The current study sample included relatively older participants, which explains the anthropometric differences: slightly heavier weight and broader Waist Circumference. Under the current unique circumstances (recruiting civilians and available military personnel on post), this was unavoidable. In all, it was concluded that the current study sample is adequate with more variability to elicit valid results.

Mobility Metrics Relative to Brassiere Design and Mobility Level

The mobility metrics of Discomfort, Interference, and Support were rated on 5-point Likert scales. Frequencies of responses as well as mean ratings per motion by configuration were computed (Norman, 2010). Then, based on the means for each metric, the best and the worst configuration per motion was selected (See Table 5). If the means were identical, then the distribution

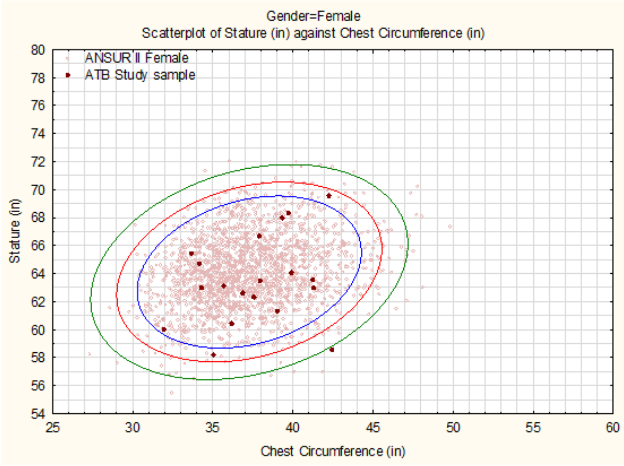


Figure 2: Stature and Chest Circumference distribution of participants relative to the U.S. Army population with 90% (blue), 96% (red) and 98% (green) ellipses.

Table 5. Best and worst configuration per mobility metrics relative to six motions.

Mobility Metrics	Six Motions	Low: Extend & Flex	Low: Rower	Medium: Windmill	Medium: Quadra-plex	High: Mountain Climber	High: High Jumper
Discomfort	*Best*	A	A	A	A	D	D
	Worst	*C*	*C*	*C*	*G*	*C*	*C*
Interference	*Best*	A	D	D	D	D/F	D
	Worst	*C*	*C*	*C*	*C*	*C*	*C*
Support	*Best*	*E*	*D*	*D*	*C*	*D*	*D*
	Worst	A	A	A	A	A	A

of frequencies was compared. The configuration with greater frequency of higher ratings was selected. If both mean values and the frequency count were identical, both configurations were listed.

Configuration C was listed 12 times; it was selected as the best supporting brassiere during Quadraplex motion, but listed as the most uncomfortable brassiere for almost all motions except for Quadraplex, and the most interfering brassiere to all motions. Configuration A was listed 11 times; it was selected as the most comfortable brassiere for low and medium level motions and the least interfering brassiere for Extend and Flex motion, but listed as the worst supporting brassiere on all six motions.

It is understandable that a brassiere with less (to no) adjustability and compression, Configuration A, would not support breasts during movement, but can be comfortable to wear without interfering with motion. Similarly, a brassiere with high compression with sufficient adjustment to tighten (Configuration C) would support the breasts but also cause discomfort and interference.

Thus, it was very interesting that Configuration D was listed 11 times as the best brassiere on all three mobility metrics; it was selected as the most

Table 6. Differences among configurations on selected anthropometric dimensions.

Unit: mm	A	B	C	D	E	F	G	Avr.	Sig.
Chest Height	1164	1180	1179	1176	1171	1180	1184	1176	**
Depth difference (Chest-Underbust)	54	57	44	53	51	56	52	53	**
Circ. difference (Chest at Scye-Underbust)	167	196	176	186	181	191	211	187	**
Circ. difference (Chest-Underbust)	165	192	152	171	150	168	193	170	**
Center Neck Drop	89	136	114	85	122	119	112	111	**

**Significant at α =.01 (26 comparisons, adjusted α = .00038)

comfortable brassiere for the high level motions (Mountain Climber & High Jumper), the least interfering brassiere for all motions except for Extend & Flex motion, and the best supporting brassiere across all three levels of motions, specifically both high level motions.

Objective Description of Design Feature of Configuration D

Circumferences and depths in bust and underbust areas are good indicators for the compression level of brassieres, where circumferences and depths tend to be smaller with high compression brassieres. Chest Height is a good indicator of breast support, as larger Chest Height indicates an elevated Thelion level, which represents a brassiere design with high breast support.

In looking at these dimensions across the test brassieres, Configuration D, a compression cup structure with straight strap, tended to be close to (or identical to) the mean values on all traditional anthropometric and derived dimensions relative to the other configurations. This indicates that Configuration D does not offer an extreme level of compression and breast support. Comparisons on the selected anthropometric dimensions are represented in Table 6.

One exception to this trend was the Center Neck Drop (refer to Figure 2), which quantified the exposure at the upper chest. Configuration D had the smallest Center Neck Drop value, indicating that it covered the most area on the upper chest relative to other configurations. Based on the mobility metrics as well as the exit interview with TPs, this design feature did provide extra comfort and support during the mobility assessment with the least interference and discomfort.

CONCLUSION

The current paper summarizes selected results from the first phase of the ATB study with two specific research questions: 1) was there a clear trend in brassiere design linked with discomfort, interference and support? 2) if so, is it possible to objectively describe those design features?

Based on the metrics of support, discomfort, and interference, Configuration D, compression with straight strap, was the most supportive brassiere with the least discomfort and interference. The design features of Configuration D were also documented in terms of anthropometric characteristics including coverage at chest area.

LIMITATION AND FUTURE DIRECTION

Selection of Mobility Tasks

The biggest challenge in selecting the mobility tasks was to eliminate tasks that would generate a great amount of aerosol in order to follow COVID restrictions. All the mobility tasks selected for the current study did not take more than 60 seconds to complete to control the aerosol (breath) produced. The tasks were all adequate for the lab testing, however, the variability in the subjective ratings was limited. If the scope of the study can be expanded, repeating the study with additional exercises conducted for duration of time, such as jogging or 1-hour power yoga will be considered or issue to wear by the individuals for an extended wear period (e.g., 1 week – 4 months) as they conduct their normal exercise activities.

Metrics for Mobility Tasks

For this study, the metrics to evaluate breast support were limited to subjective ratings. Subjective rating is an efficient scale; however, measuring consistency across configurations and quantifying the breast support or breast movement reduction are not feasible. Recently, the authors acquired a 4D whole-body system that continuously captures the 3D images up to 2 minutes at 60 frames per second. By analyzing the skin deformation captured during mobility assessments, quantitative assessment on breast movement will be feasible and applicable to better understand brassiere support.

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