IMPROVED FIT AND PERFORMANCE OF FEMALE BULLETPROOF VESTS

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The body armor for military personnel should provide a balance of protection and comfort. For both men and women, if body armor does not fit correctly and provide adequate coverage, it can adversely affect the safety and effectiveness. The design and manufacture of the body armor for female officers can present issues of particular concern. For now, Romania's female soldiers don't have any other choice than to wear men's body armor of smaller sizes, even though their body shape is different. For many women, that means wearing a standard issue vest that is tight across the torso and too loose around the middle can cause discomfort and offers less protection. The aim of the project was to develop a new protective bullet proof vest that is manufactured taking into account the female body shape, that provides comfort, mobility and adjustment possibilities, while superior ballistic resistance properties will be similar to the existing body armors. For morphological characterization of the target group, the women recruited in the national defense system, it was made an anthropometric survey using 3D scanning technology the human body in order to provide the necessary body size database to design the ballistic body armor. From primary anthropometric data we extracted the body dimensions required in designing the protective bullet proof vests. The novelty in the body armor design consist in taking into account the shape and cup size of Romanian female body. For the determination of the cup size we selected these critical dimensions: bust and under-bust circumferences.

Keywords: Body armor, anthropometric survey, female bulletproof vest, 3D simulation.

INTRODUCTION

The main function of the bulletproof vests is to provide protection, in order to reduce the impact and prevent the penetration of weapons of any kind. Women's participation in various activities that were previously allowed only to men grew over the years. Thus an increasing number of women are employed in jobs that require high physical stress, such as military or fireman. Since women are not the majority, the equipment they wear has not been specially designed for use by them. Historically, all uniforms and protective equipment for military and paramilitary personnel have been designed taking into account the sizes of the men personnel. Additionally, most manufacturers design bullet proof equipment for certain types of threats and not for certain users (Chen and Yang, 2010). Women working in the military field are ordered to wear bullet proof equipment that does not correspond with their body shape. As the responsible for US Programme for bullet proof equipment for female staff it must be taken into consideration that "women are not small man". Current studies, made by the US Department of Defence (DoD) shows that when the bulletproof vests are worn by women, there is a free space between the breasts and the protection panel, and this free space can be large enough to fit a grenade, creating an additional risk for women soldier. The smallest size of bulletproof vest is too wide or too long for 85% of female personnel. Moreover it is difficult to breathe due to pressure from the front ballistic

panel on the chest area. These factors increase the risk of injury for women who wear these types of bulletproof vests. There are several properties of the bulletproof vests that define them. Of these impact resistance and comfort, defined as body adjustment and mobility are the most common and most necessary needs of wearers of such equipment. Nowadays we cannot talk about the design of new, comfortable and ergonomic bullet proof equipment without performing in-depth anthropometric studies.

The aim of the project was to develop a new protective bullet proof vest that is manufactured taking into account the female body shape, that provides comfort, mobility and adjustment possibilities, while superior ballistic resistance properties will be similar to the existing body armors.

METHOD

For the morphological characterization of the target group for women in the national defence system, in order to provide the necessary database for designing the bulletproof equipment, as part of the project, an anthropometric survey was performed by using 3D body scanning technology. The equipment used in performing the anthropometric survey is a mobile system 3D Body Scanner VITUS XXL Anthroscan Professional based on laser triangulation optical system technology. 3D scanning methodology complies with *EN ISO 20685:2005*-3-*D scanning methodologies for internationally compatible anthropometric databases.* The standard protocol is to use 3D surface scanning systems in the human body shape data acquisition. Measurements that can be extracted from 3D scans are according to: *ISO 7520-1:2008 Basic human body measurement for technological design-Part 1: Body measurement definitions and landmarks and ISO 8559:1989 Garment construction and anthropometric surveys-Body dimensions*.

Following the established protocol of body scanning, there were measured by 3D scanning a number of 105 subjects, women in the national defence system (Niculescu *et al.*, 2010). The 150 3D sizes automatically retrieved during a scan for each of the 105 subjects were stored in a database. 56 anthropometric sizes of the 150 sizes measured in 3D scanning were selected and described and will be subject to statistical analysis.

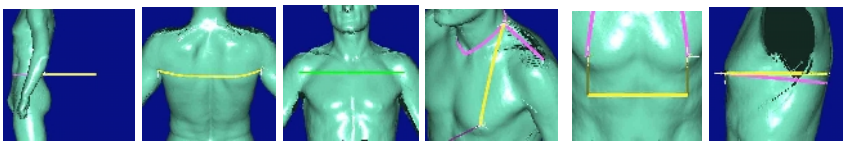


Figure 1. Examples of selected anthropometric sizes

After completing the anthropometric survey, each anthropometric size selected for morphological indicators specific to the target group is subject to unidimensional statistical processing by using EXCEL software package. The calculated statistical parameters allow the anthropomorphological assessment of women in national defence system and the establishment of a primary database required in the design of protective bullet proof equipment.

From primary anthropometric data resulted from the pilot sample scans, there were extracted the body sizes required in designing the protective bulletproof vest: bust and

under-bust circumferences. The dispersion diagram and the correlation between the two body sizes are presented in Figure 2.

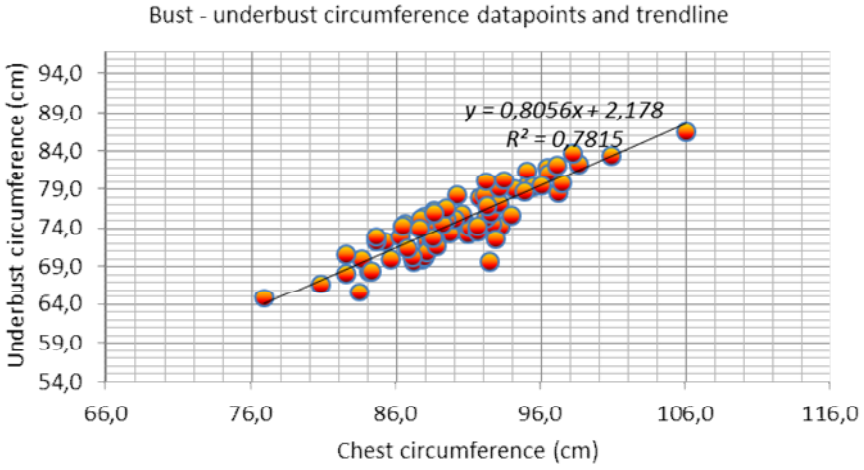


Figure 2. Dispersion diagram and regression line

The age group of the pilot sample under anthropometric pilot survey is 18-23 years. The cup size distribution in the pilot sample is shown in Figure 3.

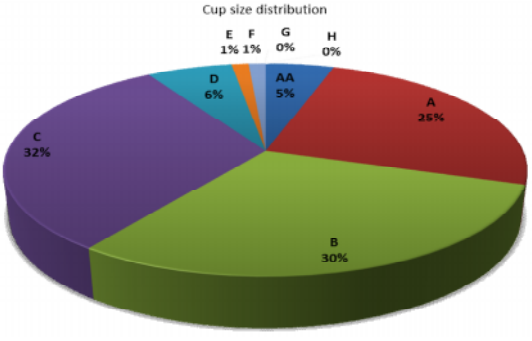
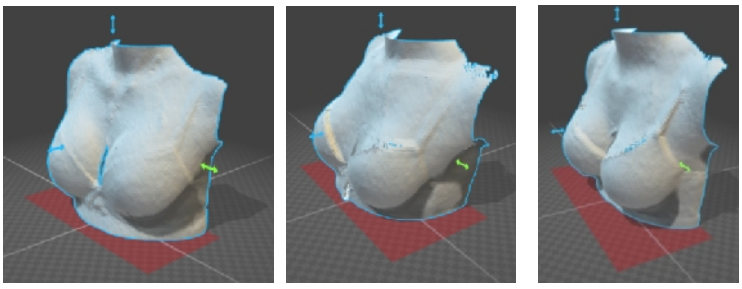


Figure 3. Cup size distribution

Cup size distribution analysis of the pilot sample presented in Figure 3 showed the highest percentage for cup size C (32%), followed by size B (30%) and size A (25%). Anthropometric data of the pilot sample, selected as needed to design the bullet proof vest for cup sizes with the highest frequency, was subjected to statistical analysis by calculating averages on both the total sample and the representative sample of each type of cup.



Cup A Cup B Cup C

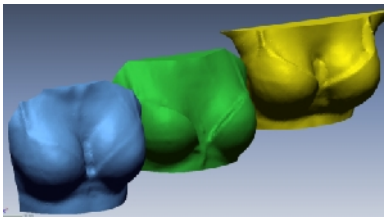


Figure 4. 3D shapes of avatar body anterior parts a) size S cup A, b) size S cup B, c) size M cup C

It was established the size of bulletproof vest presented in Table 1.

Table 1. Size of bulletproof vest

Body sizes		Size of bulletproof vest		
Bust circumference, cm	Waist circumference, cm	Size	Cup Cup size	Note
87-89	68-72	S	A	For bra 75, cup A
89-91	68-72		B	For bra 75, cup B
91-93	73-78	M	C	For bra 75, cup C

The functional model of bulletproof vest was developed for size S cup A, in accordance with anthropometric measurements of this size. Matrices for preforming the ballistic package were made in accordance with 3D shapes of the anterior parts of the avatar bodies corresponding to size S cup A and B and size M cup C, Figure 4 a) b) and c).

The physical development of the functional model by STIMPEX SA was preceded by its virtual development using solutions for digital design of the vest patterns, modelling and 3D simulation of the vest on an avatar from the sample scanned corresponding to size S. It was used the software suite OptiTex. The virtual development of the functional model was made in two versions:

V1: *3D knitted inner layer* with a mass of 756 g/m^2 and a thickness of 6.31 mm followed by *ballistic protection package no. 1* with a thickness of 5.93 mm and 4,000 g/m^2 (formed of 20 layers of Twaron fabric CT 709);

V2: *3D knitted inner layer* with a mass of 756g/m^2 and a thickness of 6.31 mm followed by *ballistic protection package no. 2*, with a thickness of 2.7 mm and 1800 g/m^2 (formed of 9 layers of Twaron fabric CT 709).

The steps to develop the virtual functional model were: a) 2D pattern design from data in the dimensional table of the model and in correlation with the real sizes of protective bulletproof vest using Pattern Design Software (PDS) from OPTITEX; b) Simulation bulletproof vest functional model on the avatar using Optitex 3D Suite Software; c) Evaluating the fit of the product on the body, such as the distance between the textile material and the body surface, tensions developed in the textile material and their orientation by using 3D software functions such as tension scale, technical characteristics of the material.

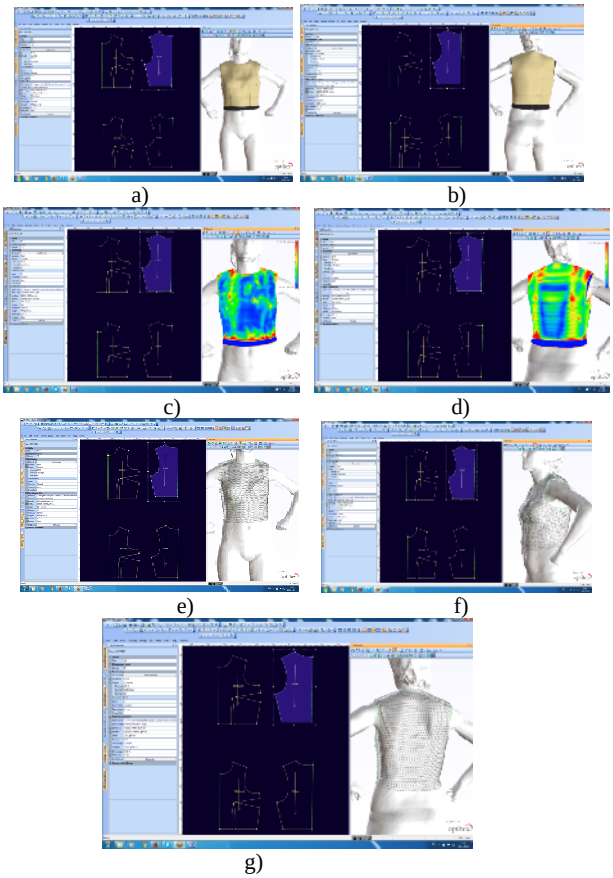


Figure 5. Simulation of the vest developed from the ballistic package 1 on the avatar a), b) checking the aspect of the vest front / back, c) and d) checking the matching body-product, e), f) and g) 3D visualization of the vest as a mesh of triangles

Checking compliance of the functional model with the anthropometric survey results revealed the following:

- patterns of the vest in ballistic package 1 and ballistic package 2 should be modified by increasing the length of the front side and the back of the vest;
- rechecking patterns of the vest in ballistic package 1 and increasing the addition of looseness;
- rechecking the simulation and a new evaluation of the correspondence body-product.

CONCLUSIONS

The body armor for military personnel should provide a balance of protection and comfort. For both men and women, if body armor does not fit correctly and provide adequate coverage, it can affect safety and effectiveness.

Designing, manufacturing and testing female specific body armors present a complex technical challenge. A material that works perfectly well as a flat armor may not perform well when subjected to folding, cutting, stitching or even changes in the stresses in the materials as it is shaped to provide protection. Additionally, there are comfort factors that impact the wearability of armor, and if an armor is uncomfortable, it is less likely to be worn, leaving the officer unprotected.

The female body armour technologies need to provide the right shape together with the right ergonomics for the benefit of female wearers in terms of protection, wearability and comfort.

The possibility to check the aspect of the product and how it is matching on the 3D model of the human body, without requiring physical development of a prototype is the main advantage of the virtual prototypes. If the product does not fit properly on 3D surface of 3D model (dummy/ avatar), the designer can easily modify the shapes of the parts and then check the new shape by repeating the steps of 3D simulation process in virtual space.

Acknowledgement

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*** OptiTex 3D Suite. Available from: http://www.optitex.com.