A Comparative thermophysiological study in sport bras for running

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Abstract. Comfort in clothing is essential for user's performance and is considered as a quality factor when choosing a particular piece of garment. Sportswear's need include comfort and functionality, meaning that the thermo-physiological properties are of extreme importance. The aim of this work consists in comparing six different models of sports bra used specifically for running, taking into consideration the aspects of the thermo-physiological properties, air permeability, moisture behaviour, and friction. This paper is part of an ongoing research aiming to establish a comprehension about function and comfort characteristics for sport bras and propose a new bra with improved characteristics both in ergonomics design as well as in comfort performance. The thermal characterization of different regions on each bra were tested using Alambeta apparatus, Textest FX 3300 for air permeability and Frictorq for friction. Evaporation tests were also carried out in different regions on each bra at 37ºC corresponding to internal temperature of the human body. The results show that raw material, structures and construction can have influence in the properties studied.

1. Introduction

Comfort is one of the aspects of higher interference about sports performance. The comfort is influenced by humidity in outside and inside clothing, temperature, humidity and body temperature as well [1]. Market surveys demonstrate consumers consider comfort as one of the most important characteristic of decision-making when they buy clothings [2].

Many studies have been made in particular taking into consideration the ergonomic issues related with sport bras. Compression effect, breast displacement and breast pain have been studied for different sport activities, from low to high intensity, resulting in recommendations concerning not only the sports bra design [3,4], such as shoulder bra strap [5, 6], compression on some situations [7], cup encapsulation [8], and the kind of sport or activity [8, 9]. Previous research has shown that the amount of contact an item of clothing (such as a sport bras) has with the skin may affect thermoregulation [10]. When the clothing fits tightly, there is less exchange of air beneath the clothing with the environment ('flushing'), and this can negatively affect thermoregulation [10]. Structures with dynamic transfer properties placed in specific regions such as cup can have a positive impact concerning the decrease of temperature on those regions [11].

2. Materials and Methods

Six different commercially available sport bras for running were analysed. Through visual inspection, the observed differences were about the kind and number of knitted structures used and the raw material. In fact there were products with a single structure used in the entire bra, bras with from two up to seven different structures, and solutions presenting one or two layers in different regions. The explanation given by the manufacturers about using more than one structure is related with comfort and functionality. Although in most of the cases the comfort issue is the reason for a proposed

structure, there were also manufacturers that claim that specific structures improve the sports bra's stabilization and thermal performance. It was also observed that almost all products used polyamide and elastane as main raw materials, with small differences in percentage from one bra to the other. It is important to note that no information is available concerning finishing or special fibres used in these sport bras.

The tested regions are illustrated in Figure 1 and were Right and Left Breast (A, B), Middle Front (space between breasts, C) Right and Left side (D, E), and Back (F). The thermal conductivity, thermal resistance and thermal absorptivity of the different regions on each bra were used to characterize thermal comfort and were carried out using Alambeta instrument according to ISO EN 31092-1994 standard procedure. For air permeability, Textest FX 3300 instrument was used according to NP EN ISO 9237 standard procedure. The surface area tested is 20 cm². In order to measure friction, Frictorq instrument was used. In this study, evaporation tests were also carried out in different regions on each bra at 37ºC, corresponding to internal temperature of human body. In this test, the bras were weighed and 20% water was placed on the specific regions of the dry bra's (Right and Left breast, Middle front, Right and Left side, back and welt).The bras were then dried in an oven at 37 °C and the mass loss was measured at 15 minutes time intervals until the water evaporated completely.This test was carried out as described by Onofrei H et al, however with some modifications in the practical procedure [12].

Table 1. General characteristics for the six sport bras.

| Code	Composition	Layers	Number of Structures
Bra 1		2	Two different structures, one in the front and other in back of the sport bra
Bra 2	Polyamide 96% Elastane 4%	2	Sport bra with two layers, with different structures in the cups, sides, back and welt
Bra 3		2	Three different structures in back, side and cup with a foam for breast support
Bra 4	Polyester 43%, Polyamide 38%, Elastane 4%	2	Two different structures in the front and back, cup with a foam layer with holes for breast support
Bra 5	Polyamide 96%, Elastane 3%, Polipropylene 1%	1	Seven different structures in distinct regions
Bra 6	Polyamide 70%, Elastane 30%	2	Only one structure in the entire bra

Figure 1. Tested regions of the sport bras.

3. Results and Discussion

Before presenting the results obtained, one should note that some regions were not possible to be tested due to the available area on the sport bras. For example, there are bras with different structures used between cups. In some situations, the available area was too small to be correctly measured with the instrument's heads. Other bras present the same structure in the front side of the bra and sides,

resulting in basically the same result. Since there are two repeated regions, only four regions are illustrated in the following figures.

3.1 Thermal Conductivity

Observing the results obtained, there are no statistically significant differences for thermal conductivity when considering the regions within the same bra for sports Bra 1, Bra 2, Bra 3, Bra 5 and Bra 6. Sport Bra 4 presents however different results in the regions of the back and the cup, front and side. This is due to the fact that Bra 4 has one layer on the back and two layers on the remaining regions. Bra 5 presents several different structures, however the results obtained are not significantly different, unless for the side region. Considering the global results between the bras, one can observe that Bra 3 presents the lowest thermal conductivity as a whole. On the other hand, Bra 1 and Bra 5 present higher values in several regions. The back region of Bra 3 and 4 presents the lowest thermal conductivity of all regions tested and there are more than one different structures with high values.
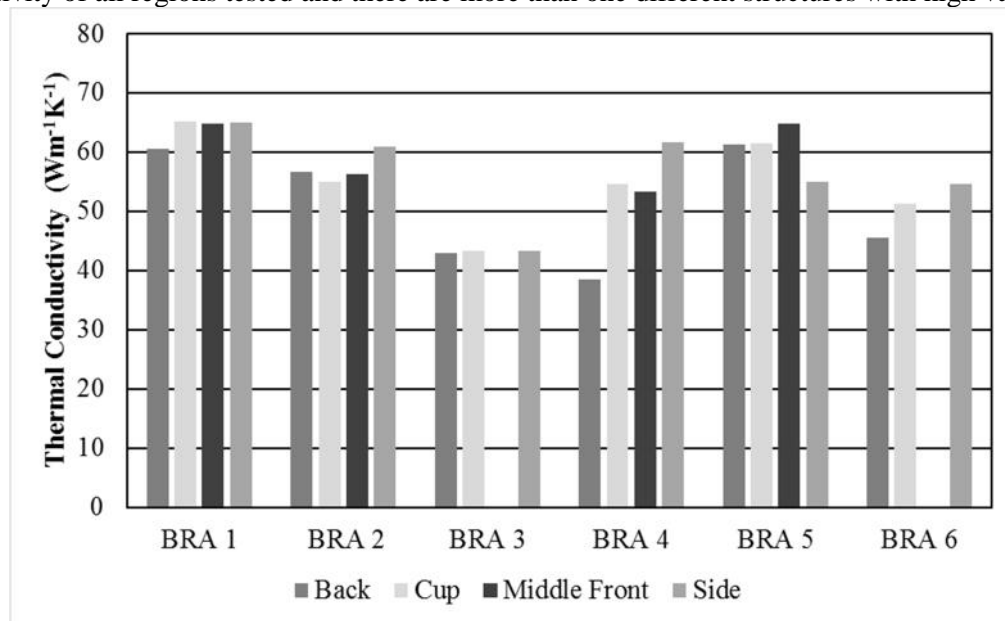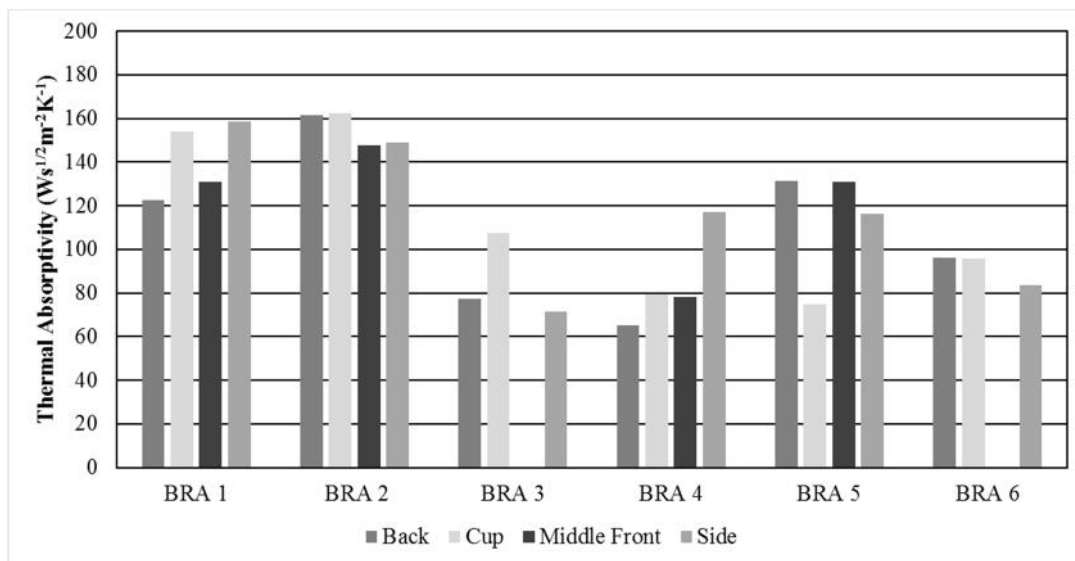

Figure 2. Mean values of thermal conductivity for the studied regions on the Bras.

3.2 Thermal Absorptivity

The thermal absorptivity is a surface property which allows to define the material´s character in terms of "cool/warm" feeling sensation when human skin briefly touches the material [13, 14]. In this sense, a low thermal absorptivity value means that the material is warm and a higher absorptivity value means that it is cool.

When considering each sport bra and analyzing the different regions, Bra 1 present similar values for Back and Middle Front regions, which is consistent with the fact that the structure is the same in those regions. The same happens with Cup and Side regions, however the structures are not similar. Bra 3 presents differences between the Back and Side regions to the Cup region. Bra 4 show statistically different values for the regions, except in the case of Cup and Middle Front with similar results. The major difference observed for Bra 5 is the Cup region. Bra 6 does not present significant differences. When comparing the sport bras as a whole, Bra 2 represents the case with highest thermal absorptivity, followed by Bra 1. For the lowest values, Bra 3 and Bra 4 seem to be the best candidates.
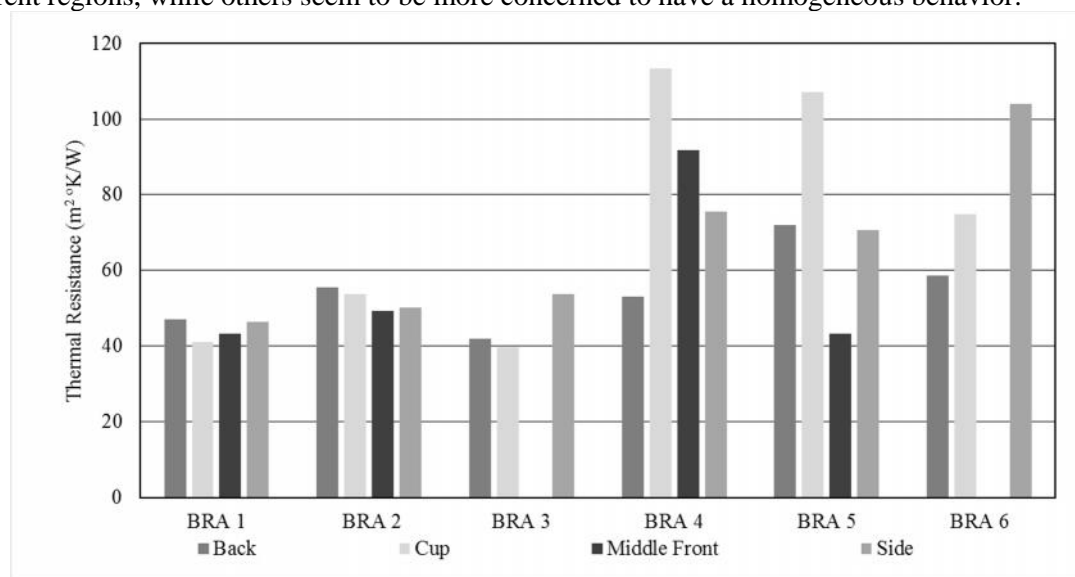
It is interesting to observe that the structures on Cup region of Bra 5 and Bra4 present the lowest values for thermal absorptivity, while for Bra 1 the value is the highest. Also Bra 3 and Bra 4 present the lowest value for the Back region, While Bra 2, Bra 5 and Bra 1 the highest. Bra5's Middle Front structure seems to have an effect in this property since it presents a high value, together with Bra 2 and Bra1 .

Figure 3. Mean values of thermal absorptivity for the studied regions on the Bras.

3.3 Thermal Resistance

Thermal resistance allows us to understand the ability of a body to prevent heat from flowing through it. For stable conditions, a fabric with low thermal resistance will result in a sensation of coolness [13,14]. The fabric structure can have an important role in this property. From the results obtained, when comparing the regions and considering each sport bra at a time, one can observe that Bra 1 present slight differences in each region, but they are not statistically significant. In the case of Bra 2, there are differences with statistical significance between the regions with higher value and the regions with lower values. Bra 3 presents a difference on the side region when compared with the others. Bra 4 and Bra 5 present in both cases differences with statistical significance for the four regions. In the case of Bra 6, due to the variability of the samples, one can only say that there is a difference between the Side and the Back and Cup. Considering the bra as a whole, Bra 1, Bra 2 and Bra 3 present the lowest thermal resistance of all bras in this study. Bra 4 and 5 present the most significant variability in their regions. One can also easily observe the absolute highest and lowest values for each region in Figure 4, being expalined by the different strutures present in Bra 5 and layers in Bra 4. It is interesting to observe that there is a concern in some of the sport bra to provide different thermal resistances for different regions, while others seem to be more concerned to have a homogeneous behavior.

Figure 4. Mean values of thermal resistance of bras used in study.

### 3.4 Static and kinetic friction

It is interesting to observe the results obtained for friction. The samples were tested using Frictorq equipment. Due to the dimensions required to perform the test, only Cup region was tested. Bra 3 was not able to be tested due to slippage difficulties between the two layers used in this bra. The results are illustrated in Figure 5 and one can observe that although dynamic friction presents similar values, when considering the static friction, one can observe the highest values for Bra 5 and Bra 6. The higher the value, particularly in static friction, the more difficult will be to start movement between two surfaces. This may be of importance since breast movement result in abrasion on skin and as consequence may cause skin lesions and pain to the user. The selected structures seems to contribute to the increase of this property.
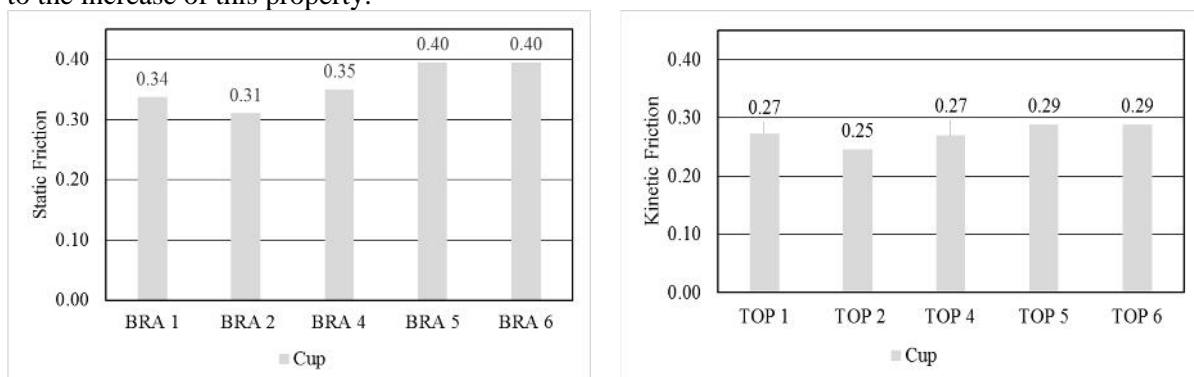
Figure 5. Static (left) and dynamic friction average values for the Cup region in bras used in this study.

3.5 Air permeability

This property allows to understand how much air may pass through the fabric. High values means that it may be easy to air to pass through, and vice-versa. From the results observed, Bra 4 and Bra 5 present the higher values on this selection of bras. In fact, the Back region of Bra 4 presents a value of more than 3000 l/m^2/s. This is due to the structure used, which consists in a warp open knitted net. The structures used in Bra 5, allow it to obtain values of air permeability that are very much higher than the remaining bras, excepting the case of Bra 4. It is also important to mention that Bra 5 has one layer.
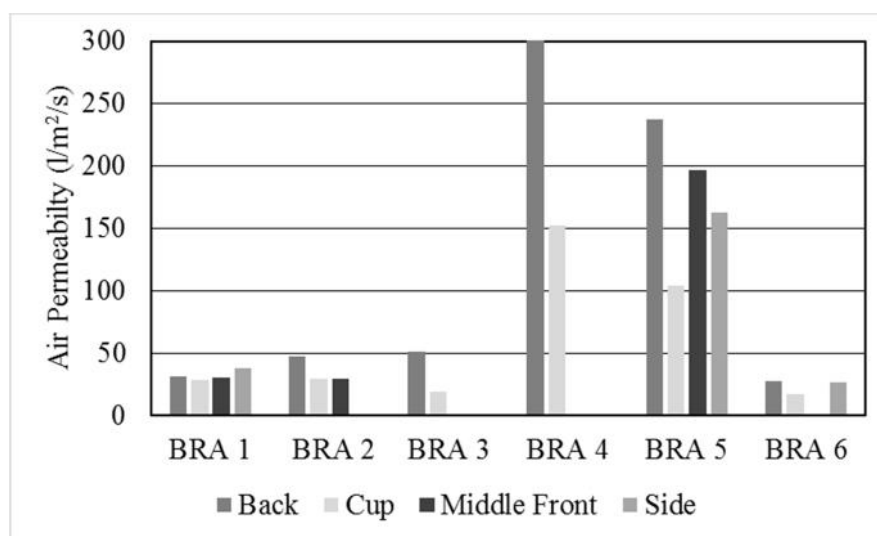

Figure 6. Air permeability average values of Bras studied.

3.6 Water evaporation
Under normal conditions, the human body has an internal temperature of 37ºC. Since the bras used will be in direct contact with the skin, which has a temperature regulated by the internal temperature of the human body, it will be important to evaluate the bras water evaporation behavior in these conditions.

Regarding the comparison for each bra, one can observe that considering the global results, Bra 3 presents the water evaporation rate that more quickly becomes dry (Figure 7). The results obtained showed that Bra 3, in terms water evaporation performance should possibly be the most comfortable.
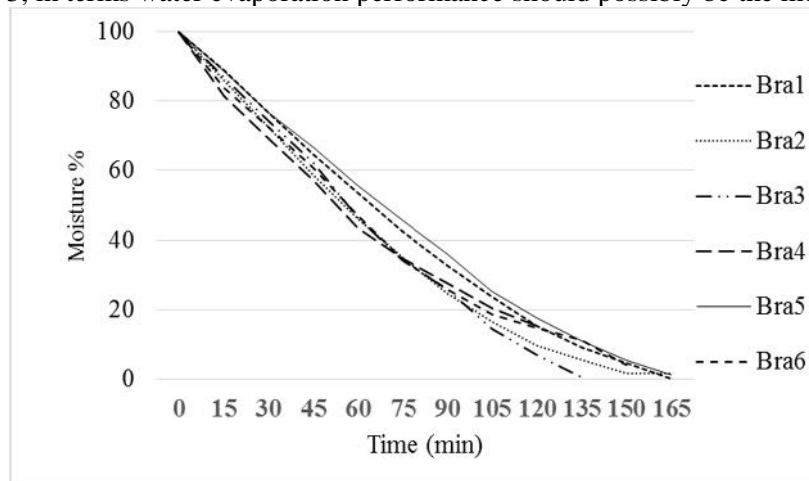
Figure 7. Bras **e**vaporation behaviour study carried out at 37ºC.

4. Conclusions
Six sports bra were characterized in this study. From the results obtained, the combination of fiber materials, layers and construction of each sport bra showed influences in the performance in terms of the properties analysed. When comparing regions within the same product, two sport bras in particular presented evident differences, which shows an intention from the manufacturer's side to fine tune specific properties on those areas towards an adequate comfort for the user.

Acknowledgments

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