Approach Towards Design of Functional Sportswear for Improved Human Performance

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Abstract Contemporary design and production of textile and clothing is focused on development of products with innovative characteristics and hi-tech functionalization for improved human performance. Therefore, an important innovation area is the R&D of specifically engineered materials and assemblies. The research is directed towards delivery of a pre-defined performance or functionality to the user, over and above its normal functions. This paper gives review of the state-of-the-art research in the area of functional sportswear design and discusses niches for the innovations beyond. The experimental part covers evaluations within three crucial segments, i.e. thermophysiological comfort of material observed trough the permeability index, thermophysiological comfort of single layered sportswear observed using thermal camera and sensorial comfort of single layered sportswear material. The test results are supported by regression models. Throughout the discussion and conclusion is outlined the need for comprehensive and systematic approach towards design and further evaluation of sportswear in order to enhance and augment body functions.

Keywords Functional · Sportswear · Temperature · Permeability index · IR thermography

1 Introduction

Contemporary textile and clothing producers are focused in development of products with innovative characteristics and hi-tech functionalization that can represent an important added value. The properties and the characteristics that were initially developed for products for special use are nowadays often present in textiles for everyday use which can be distinguished by multiple functions.

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Therefore, new textile products for improved human performance are an important innovation area in the research and production of textile and clothing like sportswear and protective wear.

The term functional clothing refers to different types of clothing or assemblies, specifically engineered to deliver a pre-defined performance to the final user. Functional clothing may be classified according to the main application areas:

I. Sports clothing
The clothing is engineered with regards to the specifics of each sport, for example golf, tennis, soccer, football, basketball, baseball, swimming, diving, running, skiing, ice skating, cycling, motorcycle riding, fencing, martial arts, fitness, alpine climbing, etc.
II. Protective clothing
The clothing gives protection against mechanical impact, physical injury, drowning, heat and fire, cold, rain, electric shock, radiation, dangerous substances, etc.
III. Medical-functional clothing
This category includes healthcare/hygiene clothing, surgical clothing, therapeutic clothing and intelligent clothing.
IV. Clothing for special needs
The category includes clothing which main function is improving the quality of life for people with disabilities or special needs, like paraplegics, handicapped, the elderly, Alzheimer's sufferers, arthritis patients, incontinence sufferers, etc.

2 Aspects of Sportswear Comfort

In order to provide a comfortable microclimate for a specific end-user, designers must define specifics for each type of functional clothing as well as to obtain feedback from the practitioner regarding specific issues. Table 1 gives overview of the demands of body and sport that need to be calculated when designing functional sportswear.

According to the recent reports [1], the global sportswear market is valued at US $ 84.1 Bn in the year 2018 and is expected to touch a valuation of US$ 108.7 Bn by end of year 2025. This gives a clear picture of how important it is to direct scientific interest towards the sportswear improvement. The following segments have to be combined within this mission:

(i) optimal material characteristics,
(ii) optimized heat and moisture management through material and
(iii) increased comfort of garment.

Comfort of sportswear is a complex phenomenon that should be observed from three different main aspects:

Table 1 Demands for the design of functional sportswear

Demands of body				
Thermophysiological regulation	Protection	Anthropometry	Movement	Psychological considerations
Heat and mass transfer, insulation, environmental conditions, workload	Contact/ non-contact sport, environmental conditions, health, safety	Body measures	Postures, agility	Style, appearance, perception
Demands of sport				
Safety		Conditions		
Protection, identification, rules		Duration of activity, location, season, climate		

I. Thermophysiological comfort
Thermophysiological comfort comprises transport processes through the sportswear. Key notions include thermal insulation, heat resistance, moisture management and breathability.

II. Sensorial comfort
Sensorial comfort characterizes the mechanical sensations that could be evaluated using objective or subjective methods.

III. Psychological comfort
The psychological comfort is rather subjective. It is affected by personal preferences, fashion, different ideology, etc.

2.1 *Thermophysiological Comfort of Material*

For the decades, the major innovation in the single layer sportswear was related to the introduction of new fibers. Fabrics for sportswear also need to be specifically constructed in terms of geometry of yarn and construction of fabric, all in order to ensure enhanced performance of the wearer [2]. The above indicates the importance of further investigation of mechanical functionalization and the need to apply new approaches to engineer innovative structures [3]. It is a joint point of view that further efforts of researchers need to be given towards investigation of optimal spinning technique and sophisticated fibers to directly affect the functionality of fabrics used for targeted sportswear. A number of investigations have been carried out to describe the effect of fabric structural parameters on different fabric properties, such as thermal resistance, vapour resistance, air permeability and mechanical properties [4–9]. However, the relative contributions of each of these segments to the comfort and performance of sportswear and sporting activities remain insufficiently defined. It is a joint point of view that further studies should be conducted in order to valorize the influence of yarn and fabric parameters on functionality of materials for specific sportswear. The transfer of heat and moisture trough sportswear materials is one of the most important properties affecting human perception of comfort. In actual wearing circumstances, it is impossible to separate heat and moisture transfer through sportswear what brings out the necessity of assessing the combination of the evaporation and heat transfer.

2.2 Thermophysiological Comfort of Clothing

The knowledge and investigation of human physiology creates a crucial basis for the development of sportswear with added value that facilitates optimal performance of athletes. Over the last decade, much attention has been paid to regional thermoregulatory effectors responses in order to adapt the choice and location of material to better meet the body needs. It is confirmed that infrared thermography can be used to assess the efficiency of the clothing intervention and may be promising in both evaluating normal patterns and deviations from these patterns with body mapping whole-body or specific areas [10–14]. Preliminary results of body mapping garment designed for the upper body were promising for improved thermal comfort. The individual qualitative and quantitative information obtained by infrared thermography can be extremely valuable to assess the efficiency of specific garments at the skin interface (warming, cooling, reducing temperature contrasts), consequently leading to improvements in thermal comfort and human performance. With careful data collection and standardized undressing procedures, this opens a wide area of testing the influence of many kinds of different sportswear garments. Further studies are required to understand the influence of body mapping sportswear in the cold and development of more customized garments. Also, a good compromise must be found between heat and vapour resistance. Investigation confirmed that manipulation of local heat resistances could be combined with the manipulation of vapour resistances to maximize comfort and performance in moderate to high intensity activities where sweat production and skin wettedness are extremely important. This should lead to body mapping garments customized by function, what is additional value for the development of personalized sportswear. The knowledge of the thermal patterns under sport apparels could be extended to a myriad of clothing conditions and exercise types in order to map the similarities and differences in skin temperature distribution.

2.3 Sensorial Comfort

Consumer purchases of textiles and clothing are very often driven by visual appearance and sensory attraction, especially consumers' visual sense and sense of touch [14]. Touching a fabric is among first actions that consumers perform in order to evaluate fabric properties in order to choose a suitable fabric for garments and to estimate the performance of the fabric for its end use. Therefore, the evaluation of materials using sensory analysis has drawn much international attention [15–17]. Regarding the subjective perception of sensorial and thermal comfort, the outcomes indicated importance of human feedback in order to develop materials and clothing for enhanced performance, as well as important discrepancies in sensorial perceptions between volunteers with different demographic profile.

3 Experimental

The Experimental part of this paper covers three aspects important for the design of functional single layered sportswear, i.e.: thermophysiological comfort of material observed trough the permeability index, thermophysiological comfort of single layered sportswear observed using thermal camera and sensorial comfort of single layered sportswear material.

The permeability index, as a measure of the efficiency of evaporative and heat transport in a clothing system is a good indicator of transfer properties for porous, single layered fabrics. The permeability index (i_m) is defined as the relationship between thermal resistance and evaporative (water vapour) resistance, what is defined by the following equation:

$$i_m = 0.060 \cdot \frac{R_{ct}}{R_{et}} = 0.060 \cdot \frac{(T_s - T_a) \cdot \frac{A}{H_c} - R_{ct0}}{(p_s - p_a) \cdot \frac{A}{H_e} - R_{et0}} \quad (1)$$

where i_m—permeability index; R_{ct}—fabric heat resistance, R_{et}—fabric water vapour resistance, T_s—temperature at the plate surface, T_a—the air temperature, A—area of the plate test section, H_c—the power input during the R_{ct} measurements, R_{ct0}—bare plate heat resistance, P_s—water vapor pressure at the plate surface, P_a—water vapor pressure in the air, H_e—the power input during the R_{et} measurements, R_{et0}—bare plate water vapour resistance.

In the Experimental part, permeability index is determined using the values of water vapour and heat resistance of knitted fabrics worn as single layer that are measured on the sweating guarded hotplate [5, 6]. The value of permeability index is further correlated to fabric main properties, i.e. surface mass, thickness area and porosity. The results are presented in the form of linear regression models for all observed fabrics and separately for fabrics produced of natural and regenerated fibers.

In order to improve thermophysiological comfort of single layered sportswear, the temperature of athlete's upper body is measured after training session. The measurement is conducted using IR thermal camera with thermal sensitivity <0.06 °C and accuracy of reading ±2%. The data are processed in professional software for thermal analysis and given as average for each of 22 defined body zones.

For the evaluation of sensorial comfort of single layered materials, a group of 140 evaluators is recruited. Evaluators are asked to rank seven presented fabrics for the attributes of softness and smoothness on a scale 1–10 [15].

4 Results and Discussion

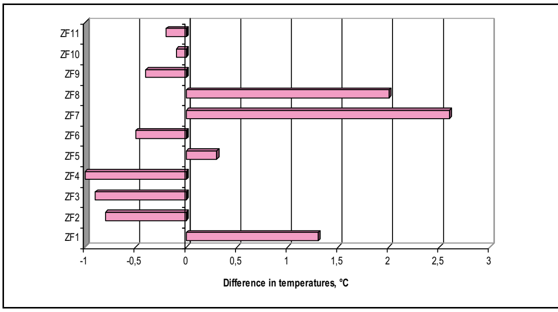
The results of modeling the relationship between a dependent variable (permeability index) and explanatory variables (surface mass, thickness and porosity) using linear regression are presented in Table 2. The changes of temperature on the surface of single layered sportswear due to activity are given in Fig. 1. In Fig. 2 are presented average ranks for smoothness and softness for seven evaluated fabrics. As can be seen from Table 2, permeability index is in the range 0.29–0.40. The results of linear regression indicate that R^2 value is high for explanatory variables surface mass and thickness in the case when the natural and regenerated materials are observed separately. Regarding the variable of porosity, R^2 value 0.9979 is obtained for group of regenerated materials only.

The results presented in Fig. 1 point out important body zones with highest change of body temperature after intensive sports activity. According to the results, this refers to the zones of abdomen, lower back and part of upper back. The results of thermographic measurements should be perceived as valuable for the definition of garment construction and should be conducted for each sport separately.

As can be seen from the Fig. 2, fabrics produced of natural fibers are perceived less soft and less smooth in comparison with other investigated fabrics. The fabric mass is perceived as negative factor for the evaluation of both smoothness and softness. In the case of smoothness, the fabric produced of regenerated fibers is highly ranked, and in the case of softness, fabrics with addition of elastane. All discussed segments of evaluation should simultaneously be used when designing sportswear in order to enhance performance and body functions.

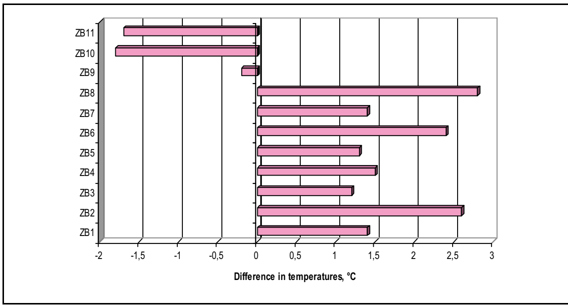
Table 2 The results of modeling

Material	Permeability index	Exp. variable	Model	R-squared
Nat.	0.29–0.37	Surface mass	y = 0.0015x + 0.1494	0.9741
Reg.	0.35–0.40	Surface mass	y = 0.0011x + 0.2377	0.9979
Nat. + Reg.	0.29–0.40	Surface mass	y = 0.0014x + 0.0174	0.6945
Nat.	0.29–0.37	Thickness	y = 0.6110x + 0.1116	0.9766
Reg.	0.35–0.40	Thickness	y = 0.6429x + 0.1443	0.9812
Nat. + Reg.	0.29–0.40	Thickness	y = 0.6032x + 0.1364	0.5601
Nat.	0.29–0.37	Porosity	y = 1.3333x + 1.3700	0.2667
Reg.	0.35–0.40	Porosity	y = 0.0011x + 0.2377	0.9979
Nat. + Reg.	0.29–0.40	Porosity	y = 0.0004x + 0.3279	0.4869



ZF11	Lt thigh
ZF10	Rt thigh
ZF9	Pelvis
ZF8	Lt abdomen
ZF7	Mid abdomen
ZF6	Rt abdomen
ZF5	Lt upper arm
ZF4	Lt chest
ZF3	Mid chest
ZF2	Rt chest
ZF1	Rt upper arm

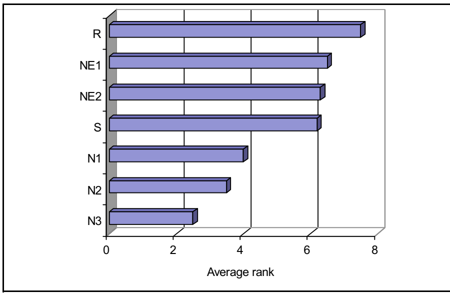
a.



ZB11	Lt thigh
ZB10	Rt thigh
ZB9	Posterior pelvis
ZB8	Lt lower back
ZB7	Mid lower back
ZB6	Rt lower back
ZB5	Lt upper arm
ZB4	Lt upper back
ZB3	Mid upper back
ZB2	Rt upper back
ZB1	Rt upper arm

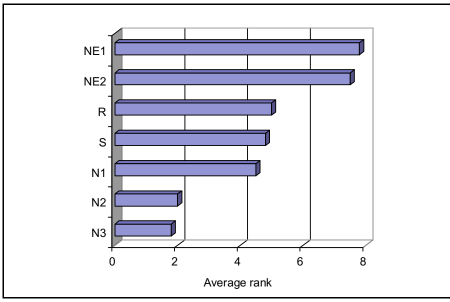
b.

Fig. 1 Changes of temperature on the surface of single layered sportswear: **a** frontal body zones, **b** back body zones



R	Regenerated, 148 g
NE1	Natural + elastane, 190 g
NE2	Natural + elastane, 176 g
S	Synthetic, 148 g
N1	Natural, 150 g
N2	Natural, 110 g
N3	Natural, 94 g

a.



N3	Natural, 94 g
N2	Natural, 110 g
N1	Natural, 150 g
S	Synthetic, 148 g
R	Regenerated, 148 g
NE2	Natural + elastane, 176 g
NE1	Natural + elastane, 190 g

b.

Fig. 2 Average ranks for smoothness (**a**) and softness (**b**)

5 Conclusion

The sportswear of today has become a truly engineered product designed to fulfill the consumer's requirements and to improve performance in sports what is tightly correlated with specifics of each sport. This paper covers evaluation of sportswear in terms of thermophysiological comfort of material and single layered garment, as well as sensorial comfort of single layered sportswear material. Throughout the discussion is outlined the need for comprehensive and systematic approach towards design and further evaluation of sportswear in order to enhance and augment body functions.

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