Clothing Comfort Under Dynamic Conditions in the Evaluation of Some Biometrics Parameters

I.The Evaluation of Energetic Consumption and Functional Frequency

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Tests on wearing clothes are complex methods of analysis that mainly consist of recording the physiological reactions in the body. An early supervision of these physiological reactions, at a physical charge and under certain climatic conditions, ergometrically shaped, provides precious information on the human body and its status, as well as on the worn clothes. Physical parameters of the environment and biometric parameters were measured during the wearing tests. There were tested 5 subjects, students, for wearing 5 textile garments. In the performed tests there were determined the following parameters: cardiac frequency, respiratory frequency and energetic consumption.

Keywords: clothing, wear tests, warm environment, dynamic conditions, comfort, evaluation, biometric parameters.

Clothing comfort is an extremely complex subject to investigate and evaluate [1-6]. Clothing, as a portable environment or a second skin, plays an important role in assisting human thermoregulation, especially in warm or extreme climatic conditions. The performance of clothing with respect to human thermoregulation should be accurately determined for ensuring adequate end uses and product development [7-10]. Biometrics factors such as heart rate and breathing frequency were measured as criteria for evaluating, in warm and hot environments, the comfort afforded human test subjects by textile apparel [11-20].

Measuring biometric indices is a way of determining the loading and tensioning the body's thermoregulation function. If, under thermal "comfort" conditions, the thermoregulatory mechanisms are modestly tensed, under other circumstances, various degrees of soliciting the body can appear, due to maintaining the effort, especially muscular, and/or to the unfavourable meteorological conditions (especially thermodispersion limitations), proper to certain ambiances [21, 22]. Distinguishing and nuancing the different types of solicitation by changing biometric units, closely connected to the thermoregulation function, complete the complex assessment of the climatic factors influences. In practice, biometric parameters are used and the dynamics of reactions in the body is measured. Some of the biometric parameters most frequently used in the assessment of the body's thermal solicitation, in warm environment, are:

- *Cardiac frequency (FC)* it is an unstable index, influenced both by the intensity of performed effort and by the variations of body temperature and other endogenous and exogenous factors. Nevertheless, being a physiological unit easy to measure and reflecting the physiological strain of the body in a warm environment, it is often used [23-27]. Cardiac frequency, FC, on a time interval Δt (min), equation 1, is defined as being:

$$FC = n/\Delta t, \text{ [bpm]} \quad (1)$$

Where n is the number of heartbeats recorded during this time interval. Cardiac frequency is expressed in heartbeats per minute, [bpm]. This value is generally counted for intervals of 1 min.

- *Lung ventilation* knowing lung ventilation allows the assessment of the energy consumption. This is based on the remark that, within certain limits of work intensity, there is a linear relationship between the lung ventilation and the oxygen consumption [28, 29]; consequently, measuring the breathing frequency allows the appraisal of the energy consumption.

Experimental part

The following determination was taken into account during the tests performed on wearing clothes: determining physical units characterizing thermal ambiance (indices of microclimate), and determining biometric indices

Table 1
TESTED PRODUCT VARIANTS

Code of product variant	Item code	Fibrous contents
Ma	G1.1	100% cotton
Mb	G2.2	33% cotton + 67 PES
Mc	H1.3	100% PES Micrell (microfibre)
Md	H5.4	100% PES, non-saponified
Me	H5.5	100% PES, saponified

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characterizing the state of the organism (comfort/ discomfort).

The clothes used during the wearing tests comprised 5 variants of female blouses, for the warm season (summer). The choice of this type of clothes was based on the fact that in general, in summer, the clothes structure covering the body most frequently consists of a blouse or dresses (one layer). A simple blouse model was chosen, without sleeves and collar, with a straight silhouette. The geometry and the openings of the product had to ensure good ventilation, which facilitates the transfer of heat and humidity and the evaporation of perspiration on body surface. The model was designed out of five different items, of class cotton type and silk type; the tested variants are presented in table 1.

Environmental conditions Tests were carried out during the summer period, in a specially designed room under the following circumstances: air temperature t_a = 25.4 – 27°C; relative air humidity φ = 57 - 79%; air currents speed v_a = 0.04 – 0.21m/s. These characterize a warm and wet environment, without any air currents; also, there was no influence from sunbeams.

The subjects were five students from the Faculty of Textiles and Leather Engineering; the imposed conditions on choosing the subjects were: close ages, similar constitution (no obese persons), and the same physical resistance, the same life style (the same education and socio-economic conditions). During wearing tests, biorhythm was also taken into account, as determinations were carried out at the same hour. When selecting the subjects, it has to be considered that there are differences between acclimatized and non-acclimatized persons, as well as between persons that are adapted to physical effort and unadapted persons. Under warm weather conditions, acclimatized persons consume less energy, the heat loss is lower and the quantity of produced perspiration is lower compared to a non- acclimatized person. Also, under the same ambience conditions, the persons who are adapted to physical effort consume a lower quantity of energy; lose less heat and less perspiration liquid compared to persons who are not adapted to effort.

Status conditions of the human body (physical charge) the physiologic experiment on subjects was carried out under dynamic conditions and comprised three distinct stages: repose and accommodation, effort and repose, and anticlimax. The length of each period has to be chosen according to the destination of tested products and envisaged aim. The physical effort was carried out on a cycloergometer, KE11. It was chosen a 60W effort, in order to obtain a cardiac frequency greater than 120beats/min and at the same time lower than below-maximum value of effort, which is of about 150 – 160beats/min, imposed conditions according to SR ISO 8996; in this way, changes pulse due to the neuro-psychic factor are avoided. Regarding the destination of the items taken into account for the research, it has been considered that aspects related to heat transfer and humidity are essential, so it was established that all three periods – repose, effort and anticlimax – should be of at least 30 min . It was established that effort and anticlimax periods should be of 10 min also in order to make the difference between the thermal component of the pulse (which under the testing circumstances recorded high values) and the mechanical work (metabolic) component. During wearing tests physical parameters of the environment and the previous mentioned physiological parameters were measured.

Evaluation of the biometric indices

In the performed tests, the following biometric indices were measured: cardiac frequency ($\overline{FC}$) and breathing frequency ($\overline{FR}$). The direct investigation of oxygen consumption was avoided, as well as recording the ventilatory debit and the electrocardiogram in order to reduce the variations of energy consumption, breathing frequency and cardiac frequency through the discomfort determined by the investigation equipment (mask or oral

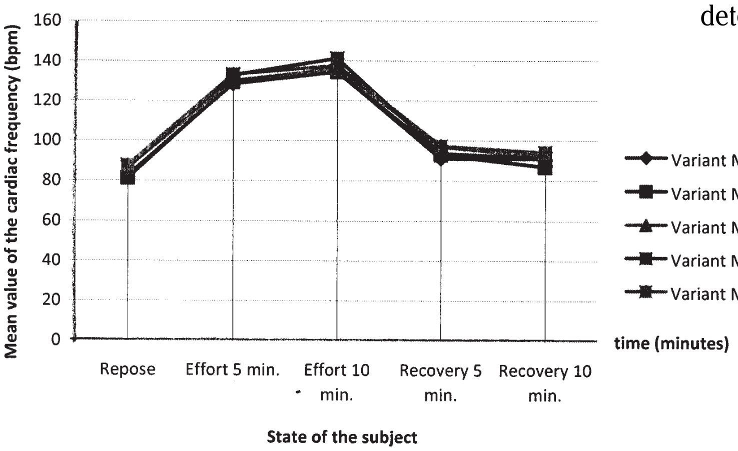

Fig. 1. Variation of the cardiac frequency ($\overline{FC}$)

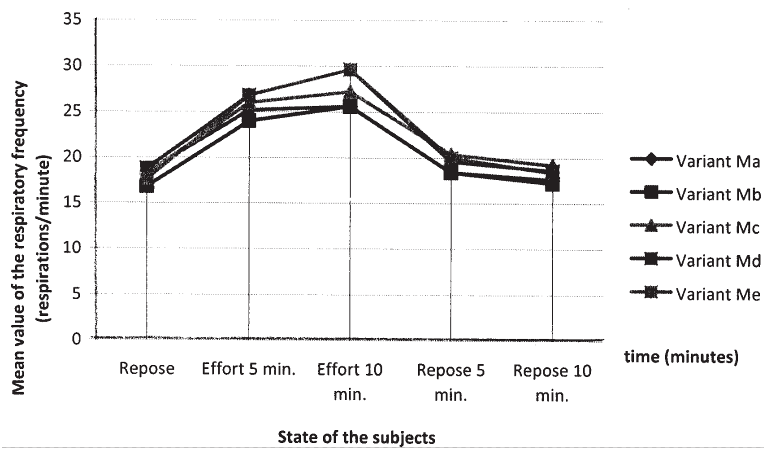

Fig. 2. Variation of the respiratory frequency ($\overline{FR}$)

Product variant	ΔFC_T (bpm)	ΔFC_M (bpm)
M_a	19.67	39.73
M_b	16.87	42.53
M_c	21.40	39.60
M_d	22.20	44.00
M_e	24.73	37.87

Table 2
ELEMENTS OF THE CARDIAC FREQUENCY

piece and electrodes fixed on the skin). At the same time, this would have modified the position of the wearing item on the body. Cardiac frequency and breathing frequency were determined every minute during wearing tests (repose, effort, and anticlimax). The average values of the cardiac frequency (FC) and respiratory frequency (FR), for the five product variants and different states of the body (repose, after 5 and respectively 10 min of effort and recovery after 5 min, respectively 10 min), are presented in figures 1 and 2.

The variation of the cardiac frequency expresses both the vasomotricity and also the heat exchange of the body with the exterior environment. For the products M_c, M_d and M_e in comparison to M_a and M_b appears since repose state the reaction of vasodilatation that prepares the heat loss. The cardiac frequency, FC, can be considered as being the amount of more elements that are not independent one of another (SR ISO 9886), (eq. 2):

$$FC = FC_o + \Delta FC_M + \Delta FC_S + \Delta FC_T + \Delta FC_N + \Delta FC_E \quad (2)$$

where, FC_0 – is the average cardiac frequency measured in repose when sitting under thermal comfort conditions, meaning a metabolically level equal with 58W/m^2; FC_0 = 75bpm; ΔFC_M – is the increase of the cardiac frequency determined by the working metabolism; ΔFC_S – is the increase determined by the static efforts; ΔFC_T – is the element determined by the thermal stress of the subject; ΔFC_N – is the nervous element often observed in the reposed subject and which may disappear when making effort; ΔFC_E – is the residual element determined by the respiratory rhythm, nictemerale cycle etc.

The respiratory element disappears to a great extent when the FC cardiac frequency calculation is achieved in a 30 s or more interval; the circadiane element may be neglected in this case. In real situations, the thermal element ΔFC_T can be evaluated only if the cardiac repose frequency FC_0 can be measured and the other elements can be neglected. In case of ceasing the muscular activity the cardiac frequency begins to rapidly decrease. After a few minutes the elements ΔFC_M and ΔFC_S resulted from activity will practically disappear and only persist the increase of thermal origin. So, the decrease curve of the cardiac frequency function of time presents a discontinuity after a certain period of recovery and the element determined by the thermal stress at the end of the effort period can be expressed by the formula (eq. 3):

$$\Delta FC_T + FC_r + FC_o \quad (3)$$

where, FC_r – is the cardiac frequency corresponding to the discontinuity moment of the decrease curve of FC; FC_0 – is the cardiac frequency in repose in neutral environment from a thermal point of view.

The recovery time until the discontinuity moment is in average of 4 min ; it can be longer if the work metabolism was higher (is not the case of the performed tests). The increase of the cardiac frequency of thermal origin, ΔFC_t, is much correlated with the increase of temperature in the central nucleus of the body (t_{cr}). The FC increase with a 1°C increase of t_{cr} is called thermal cardiac reactivity and is expressed in cardiac beats per minute and Celsius degrees (bpm/°C). The inter-individual variations of thermal reactivity can be considerable. For the same subject it also varies function of the performed effort type (and as a result of the muscular group involved) and function of the thermal stress predominantly exogenous (due to the climate) or endogenous (due to the metabolism). Its interpretation must take into account these elements. The specialty literature [24] presents the following calculation modality for the cardiac frequency elements under state dynamic conditions of the body in a warm environment, equation 4:

$$FC = FC_0 + \Delta FC_M + \Delta FC_T \quad (4)$$

Where, FC_0 – is the cardiac frequency in repose in neutral environment; ΔFC_M – is the motor element (metabolic) of cardiac frequency; ΔFC_T – is the thermal element of FC.

The ΔFC_T element can be calculated as following (eq. 5):

$$\Delta FC_T = \frac{FC_3 + FC_4 + FC_5}{3} - FC_0 \quad (5)$$

where, FC_3, FC_4, FC_5 – represent the cardiac frequencies in recovery after 3, 4 and 5 min.

So the ΔFC_M will be calculated with the formula (eq. 6):

$$\Delta FC_M = FC_{max} - (FC_o + \Delta FC_T) \quad (6)$$

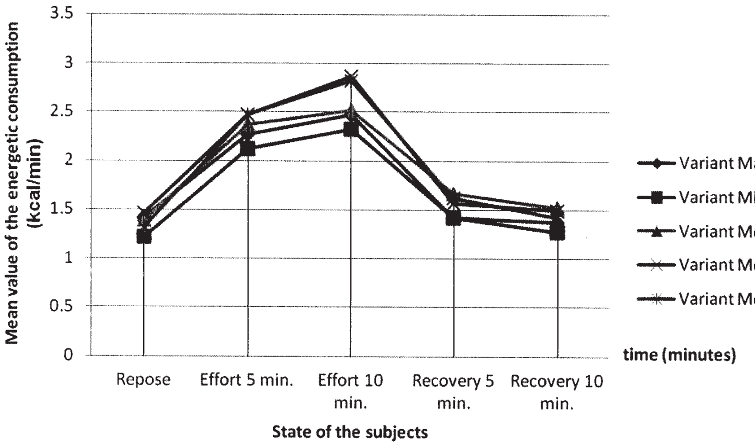

Fig. 3. Variation of the energetic consumption Ce - physical strain

Conditions of organism state	M_b		M_c		M_d		M_e	
	1	2	1	2	1	2	1	2
At rest	0.418	1.37	-0.816	0.6	-0.869	-0.53	-1.204	1.63
Effort 5min	-0.152	0.88	-0.444	-0.78	-2.06	-0.87	-1.25	- 1.63
Effort 10min	0.000	0.69	-0.375	-0.23	0.08	-1.83	-0.874	-2.06
Recovery 5min	-0.707	0.00	-1.342	0.03	-0.622	-1.5	-1.835	0.09
Recovery10min	1.05	1.00	-0.48	-1.18	-0.147	-0.53	-0.814	-1.00

Table 3
EVALUATION THE BIOMETRIC PARAMETRICS
CARDIAC FREQUENCY/ENERGETIC CONSUMPTION
(M_a compared with condition of organism state)

where, FC_{max} – is the maximum cardiac frequency (after 10 min of effort).

The average values obtained for the 5 variants of tested products are presented in table 2.

In average, the two elements represent: $\Delta FC_T \approx 21$bpm, respectively 15.33% of FC_{max}; $\Delta FC_M \approx 41$bpm and 29.93% of FC_{max}.

It can be observed that the ΔFC_M element is approximately the double of the thermal element ΔFC_T for the conditions had in the wearing tests. It can be observed that the smallest values of $\overline{FR}$ are registered for the variants M_a and M_b (in comparison to the variants M_c, M_d and M_e), almost on the entire period of the determination (for various states of the organism). The greatest values of $\overline{FR}$ is registered on effort for the variants M_d and M_e but these allow a better recovery after effort in comparison with the variant M_c. The variant M_c although has an intermediary behaviour between the variants groups (M_a and M_b) and respectively (M_d and M_e) still at recovery has the most non-corresponding behaviour (does not allow the organism to recover to the initial state not even after 10 min).

Based on the respiratory frequency it was determined the energetic consumption (Ce) in kcal/min after Romathan's nomogram. The intensity of the effort and energy consumption allows determination of the energetic metabolism measure (M) that is one of the thermal balance terms of the organisms. The variation of the energetic consumption for the 5 researched variants function of the organism state condition is presented in figure 3.

Results and discussions

The STUDENT "t" test, the formula for correlated samples, was used to differentiate the reactivity of the organism when wearing the 5 variants of product by taking into account the fact that the same subjects were investigated in five clothes variants, with five stages of measurements. The calculation relations used are (equations 7 and 8) [24-40]:

$$t = \frac{\overline{m_d}}{\frac{\sigma_d}{\sqrt{N}}} \quad (7)$$

$$\overline{\sigma_d} = \sqrt{\frac{\sum d^2 - \frac{\left(\sum d\right)^2}{N}}{N-1}} \quad (8)$$

where, $\overline{m_d}$ is the mean of differences between the data compared; $\overline{\sigma_d}$ is the standard deviation of the differences; N- the number of investigated subjects; Σd^2 –is the sum of squares of differences between the data compared; Σd – is the algebraic sum of differences between data compared.

Among the comparisons achieved at the indicators presented above between the variants analyzed (the variant M_a consecutively with M_b, M_c, M_d and M_e) were considered as significant those differences that presented a significance threshold, $p \leq 5\%$, according to the situation taking into consideration (more seldom) the significance threshold of under 10%, taking into account the small number of investigated subjects. In the tables 3 are presented the results obtained regarding the significance tests ("t"), where 1 is the cardiac frequency and 2 is energetic consumption.

In the tables there are the values of Student "t" test, and where there are significant differences from the statistic point of view the value of the significant threshold is also written (p). Regarding the average cardiac frequency, it is noticed that after 10 min of effort it is significantly higher in the case of M_d product compared to M_a one. The energetic consumption is significantly higher in the case of M_c product compared to M_a one (after 5 min of retrieval) and in the case of M_e product compared to M_a also.

Conclusions

The study presents the results of an experimental research, tests on wearing clothes; this implied the measurement of a series of physical indicators that characterize thermal environment and of a series of physiological indicators that feature the state of the body. In order to carry out these tests a group of five individuals was used, who wore five variants of the products in dynamic conditions, in a warm environment.

For the processing and interpretation of the experimental results a quantitative analysis method was used. In this analysis, due to the small number of investigated individuals, the difference of reactivity of the body on wearing the five product variants was attempted by using the STUDENT "t" test, the formula for correlated samples. From the comparisons carries out on the measured physiological indicators between the analyzed variants, the significant differences recorded were those that had a significance threshold (p) ≤ 5%. Thus the conclusion was that between M_a and M_b products there were no notable differences in any of the investigation stages; when wearing M_c, M_d and M_e products, the values of measured indicators were always higher than for M_a and M_b products, which means that M_a and M_b products are more comfortable when worn than M_c, M_d and M_e products.

It can be stated that the thermal stress for a person exposed to a warm environment depends especially on the heat production inside the body as a result of a physical activity, of the environment characteristics that influences the heat transfer between the body and ambience, of the garment product worn at that time. The internal thermal charge is the result of the energetic metabolism connected to the activity.

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