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The Comparison of Human Perception to the Measured Sweat Transfer Rate

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A B S T R A C T

The subjective investigation, that is focused on the sensations of a person, is a good tool for the evaluation of an environment that group of people consider comfortable. In the experiment reported here, participants were dressed into 1--layer and 2-layer clothing systems. They performed physical activity and rated the subjective perception of comfort, as well as the thermal and moisture sensation. The aim of this investigation is to compare the subjective human perception during the physical activity wearing different clothing systems to the objective results of sweat absorption.

Key words: *thermophysiological response, human perception, sensation, comfort, sweat absorption*

Introduction

The use of investigation with subjects (in-vivo) on the basis of the sensations of a person is one of the best ways to determine whether a group of people consider the environment comfortable or not. Methods that may be used to measure physiological responses range from psychophysical techniques, use of scales and integrated methods to behavioral measures[1]. There are several studies dealing with the investigation of the thermophysiological responses and perception of clothing comfort on the basis of the participation of subjects. The investigations were focused on the determination of the sweat distribution over the body[2–4], comparison of the responses among people of different sex and ages[5–7], as well as the investigation of the responses in a cold environment[8–10].

In our previous investigation, the sweat absorption is investigated trough the participation of subjects (responses of male and female volunteers wearing two kinds of textile fabrics) and using equipment that measures different material properties (the sweating guarded hotplate and termovision camera)[11]. The results of mass absorption obtained from the objective measurement on the sweating guarded hotplate show the similar trend as the results obtained during the measurement with subjects[5]. In this paper, the investigation continues. The aim of this investigation is to investigate the human perception of comfort and sensation of heat and moisture during the intensive activity, wearing two different clothing systems. Further more, the intention is to compare the results of reported moisture perception to the measured rate of absorbed sweat. The results should indicate whether there are bigger discrepancies between the results obtained using different methods.

Theoretical part

Human comfort is defined as the state of mind that expresses satisfaction with the surrounding environment. If related primarily to the clothing, comfort may be defined as neutral sensation, a freedom from pain and unawareness that clothing is worn. Perpendicular term is discomfort that describes a situation in which a person is conscious of the clothing that is worn and the experience of wearing is quite unpleasant. Considering the level of unpleasantness, discomfort can range from the feeling of irritation to an extreme pain. In hot and cold environments, as well as under intensive activity, the level of comfort decreases, while the level of discomfort increases. Therefore, it could be said that in such conditions, in fact, only the level of discomfort can be reported. The maintenance of comfort is depended of the equilibrium that the body has with its surroundings and is very important for a number of work-related factors, because it can significantly affect the work performance and productivity. Among the factors that determine the comfort, the following should be pointed out: environmental conditions (air temperature, mean radiant temperature, air

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movements, relative humidity, etc.), clothing properties (insulation, ability to absorb heat and moisture, air permeability, type of raw material, constructional parameters, etc.), activity level and personal factors. The last mentioned group of factors is quite complex because it refers to a wide range of factors that include health and metabolism, physiology and different sociological and individual factors such as gender, national-geographic affilation and age. Therefore, the individuals in a group of people placed in the same environment, performing the same activity, would describe the perception of comfort/discomfort differently. There are many measuring methods that are used to describe comfort characteristics of clothing under different environmental conditions, but additional tests with subjects may enhance the quality of obtained results.

The work uniform is designed to protect the body from different environmental influences. Its construction is usually multi-layered, consisting of two or more layers made from knitted or woven fabric that should be capable of trapping air and transferring moisture and sweat that is placed on the human skin. The comparison of heat and moisture transfer within four main mechanisms of transfer (convection, conduction, radiation and evaporation) for the clothing systems consisting of 1-layer and 2-layers system is given on the Figure 1. The knitted fabric, due to its structure that is formed from loops, has higher porosity than woven fabric made of the yarn of same count. Therefore, it is to expect for such structure to enable the higher sweat transfer. For the perception of optimal wear comfort, it would be favourable if the amount of liquid sweat on the skin is as low as possible, what brings out the importance of the vaporous sweat transport. The importance of optimally designed clothing is even bigger knowing that unlike the environmental conditions or human physiology, it can be altered to maximise the wear comfort.

Material and Methods

Nine male volunteers participated in the experiment. The chosen subjects have the same profession that is related to the public security maintenance. Due to the profession demands, all subjects are in good physical condition and healthy. The characteristics of volunteers are given in the Table 1. Before the start of experiment, volunteers were informed of the test procedures and all possible risks. They were requested to consume normal amounts of fluids on the day prior to the experiment and to take 0.5 litre of natural water 30 minutes before the start of the experiment. During the exercise protocol, volunteers were not allowed to drink additional liquid. The exercise protocol was the same as in our previous paper[11]. The task of subjects in this experiment was to perform physical activity that consisted of three steps: lift up a load from ground to a height of 1 m, leave the load at a bench and pull the load to the ground. This action was constantly and without pause repeated within the defined time of 5 minutes. The conditions in the room were carefully controlled. The temperature was 23.5±0.5°C and relative humidity 33±2%.

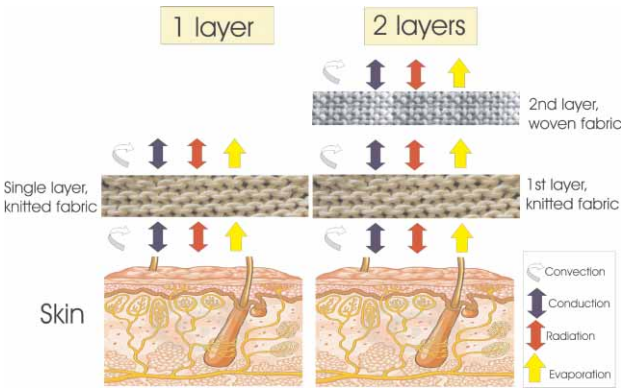

Fig. 1. Transfer of heat and moisture trough 1 and 2 layers of clothing system.

Before the start of experiment, the protocol was explained and each volunteer filled out the medical inquiry consisting of the questions related to the following[12]: heart diseases, high blood pressure, lung problems, skin deseases/allergie, problems with body motorics and medicaments they take at the moment. All participants negligee named problems.

The protocol of investigation is given in the Table 2.

During the experiment, the subjects were dressed in long training trousers made of cotton fabric in single jersey knit, cotton ankle socks and training snickers made of polyester.

TABLE 1
CHARACTERISTICS OF VOLUNTEERS

Nr.	Subject	Body mass, kg	Height, m	Age, years
1	A	93.4	178	44
2	B	140.6	175	41
3	C	99.3	182	35
4	D	92.0	192	37
5	E	95.1	180	45
6	F	112.0	176	46
7	G	106.7	182	46
8	H	92.9	171	38
9	I	94.6	174	42

TABLE 2
PHASES OF ACTIVITY PROTOCOL

Period	Time, minutes	Phases
1	0–1	Take water
2	2–32	Relaxation
3	33–35	Pressure/heart rate measurement
4	36–41	Work
5	42–44	Pressure/heart rate measurement
6	44–74	Relaxation

In the first part of the experiment they wore T-shirt produced from cotton knitted fabric, while in the second part they wore the same cotton T-shirt and additional long sleeved shirt made of cotton woven fabric. The clothing items used in the experiment are a part of their standard professional uniform. The systolic and diastolic blood pressure, as well as the heart rate, was monitored before and after the activity. In the preparatory period, the subjects were dressed and left to relax in the chamber with the conditions defined. The weight of the T-shirts was measured before and after the end of the experiment.

In order to evaluate the subjective sensation, questionnaires were given to each volunteer before the start and after the end of performed work. The questionnaire included the perception of comfort, as well as the thermal and moisture sensation. The perception and sensation were recorded on the 4-point with the following boundary terms: comfortable-uncomfortable, hot-cold and dry-very wet (Figure 2). The 4-point scale was determined after the discussion, as the most appropriate for the expression of sensation and perception for chosen group of volunteers.

a)

Comfortable	Slightly uncomfortable	Uncomfortable	Very uncomfortable
1	2	3	4

b)

Hot	Slightly warm	Slightly cool	Cold
1	2	3	4

c)

Dry	Slightly wet	Wet	Very wet
1	2	3	4

Fig. 2. Subjective rating scales: a) comfort, b) thermal sensation, c) moisture sensation.

Results

The physiological measurements include the systolic, diastolic blood pressure and heart rate measured before and after the experiment. The summary of measurements is shown in figures 3–6. Table 3 and 4 show results of subjective evaluation of comfort, heat and moisture in

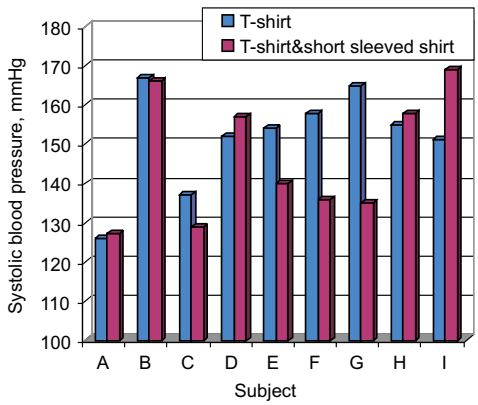

Fig. 3. Systolic blood pressure of subjects.

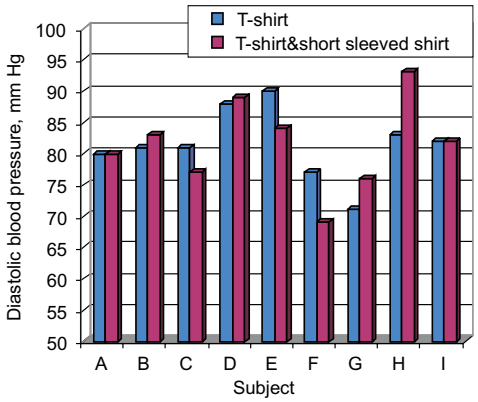

Fig. 4. Diastolic blood pressure of subjects.

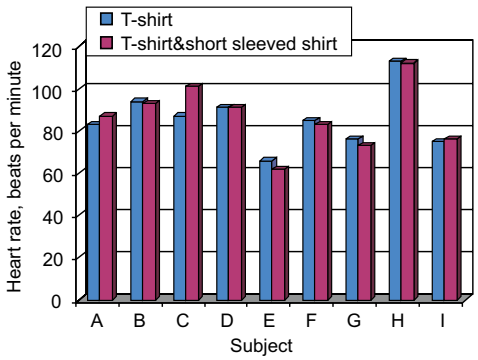

Fig. 5. Heart rate of subjects.

phases 1 (subjects dressed T-shirt, i.e. 1-layered clothing) and 2 (subjects dressed T-shirt and short sleeved shirt, i.e. 2-layered clothing). Dependence of the mass of absorbed sweat to the body mass is shown on figure 6. The comparison of rates and absorbed sweat on T-shirt (phase 1) and T-shirt and short sleeved shirt (phase 2) is shown in Figures 7 and 8.

TABLE 3
RESULTS OF SUBJECTIVE EVALUATION IN PHASE 1

Nr.	Name	Phase 1 (wearing T-shirt)					
		Before activity			After activity		
		Comfort	Heat	Moisture	Comfort	Heat	Moisture
1	S1	1	1	1	1	1	1
2	S2	2	1	3	2	1	3
3	S3	1	1	1	1	2	1
4	S4	1	1	1	1	2	2
5	S5	1	1	1	1	1	1
6	S6	1	1	1	1	2	3
7	S7	1	1	1	2	2	2
8	S8	1	2	1	1	2	2
9	S9	1	1	1	1	1	1

TABLE 4
RESULTS OF SUBJECTIVE EVALUATION IN PHASE 2

Nr.	Name	Phase 2 (wearing T-shirt and long sleeved shirt)					
		Before activity			After activity		
		Comfort	Heat	Moisture	Comfort	Heat	Moisture
1	S1	1	1	1	1	1	1
2	S2	2	3	1	2	2	4
3	S3	3	2	2	2	2	2
4	S4	1	2	1	1	2	3
5	S5	1	1	1	1	2	1
6	S6	1	1	1	2	2	4
7	S7	1	1	2	2	2	3
8	S8	1	1	1	1	2	2
9	S9	1	1	1	1	1	1

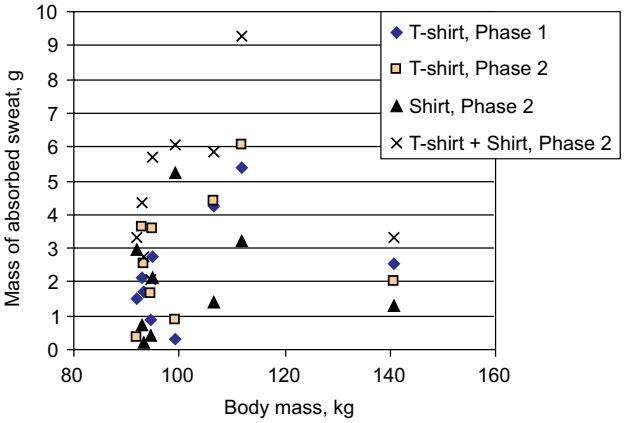

Fig. 6. Mass of absorbed sweat in dependence on body mass.

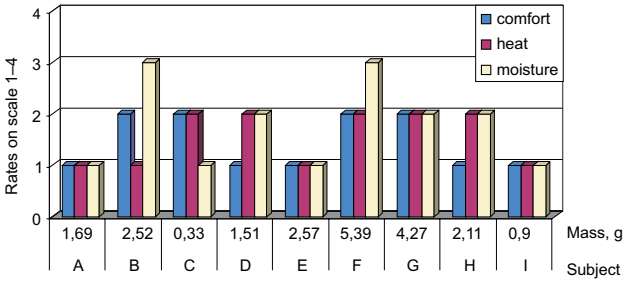

Fig. 7. Comparison of rates and absorbed sweat on T-shirt (phase 1).

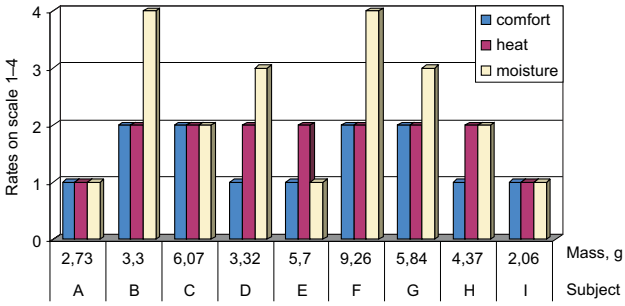

Fig. 8. Comparison of rates and absorbed sweat on T-shirt and short sleeved shirt (phase 2).

Discussion and Conclusions

In the first phase of the experiment, the subjects were dressed in T-shirts. Due to the shirt structural properties (loop density, mass, thermal insulation, etc.), the environment within the temperature range 22–28°C should for most of people be considered comfortable. As seen from the table 3, the subjects gave high rates on comfort scale before, as well as after the activity. The rates of heat sensation were quite unexpected. As seen from the table 3, eight subjects gave the rate 1 on the heat scale (meaning hot) before the start of activity. After the end of activity, half of them gave the rate 2 (slightly hot). The reason for such rates was well seen during the experiment. Namely, a part of the subjects reported before the start of experiment that they are a bit nervous because they never participated in the similar projects. Therefore, their sensation of heat was probably more intensive than it would be in the same environment under different circumstances. After the end of physical activity, they were relieved and quite satisfied with their performance, which resulted in a different sensation rate. By the end of the experiment, the sensation of moisture, as seen from the rates, increased. After the phase 2, the subjects reported the perception of slight discomfort and wettedness, while the heat sensation, due to the reasons described for the phase 1, was better. As the subjects participating in this experiment wear the same clothing assemblies every day, it is important to take account of their subjective rates in order to evaluate the clothing functionality. According to the presented results, it could be concluded that both assemblies seem to be acceptable for all the subjects regarding the comfort perception and heat sensation. Only two subjects reported a high level of moisture sensation after the performed activity wearing the second assembly. The relation between the mass of absorbed sweat and body mass is very weak (the correlation coefficient is for all the cases under 0.2).

The comparison of rates and absorbed sweat on clothing (Figures 7 and 8) indicates that the rates on comfort and heat scales are not connected to the mass of absorbed sweat (the correlation coefficient is in both cases under 0.4), as are the rates of moisture sensation (correlation is positive and rather strong; coefficient is 0.7).

Therefore, it could hardly be concluded that there is a tight connection between the absorbed sweat and given rates. The general impression of a person that collected inquiries during the experiment is that the subjects were trying to make better impression of themselves. Therefore, they used to give better rates, although it was quite obvious for an observer that some of the rates may not be in complete accordance with their real sensations and perceptions. The reason for such behaviour should be their professional drill and the effort to stand and rate

the activity better than their work partners. A certain discrepancy between the attitude of these subjects and subjects participating in our previous study[11] (men and women of different professions) indicate the possible boundaries of subjective evaluation and a need to include a psychological observation in order to explain the obtained results.

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USPOREDBA ČOVJEKOVE PERCEPCIJE I MJERENOG INTENZITETA ZNOJENJA

SAŽETAK

Subjektivna istraživanja, koja se temelje na osjetima pojedinca, su dobro sredstvo za ocjenu uvjeta okoline koje skupina ljudi percipira udobnim za boravak. U eksperimentu prezentiranom u ovom radu, ispitanici su odjeveni u odjevne komplete koji se sastoje od jednog i dva sloja. Ispitanici su vršili rad i davali subjektivne ocjene udobnosti te osjećaja topline i vlažnosti. Cilj istraživanja je usporediti subjektivnu percepciju osobe odjevene u različite odjevne komplete tijekom fizičke aktivnosti s rezultatima apsorpcije znoja izmjerene objektivnim metodama.