The application of brain activity as a method for assessment of the human thermophysiological comfort and performance in cold indoor environment

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Abstract. The paper presents a pilot study on the influence of cold indoor environment on the activity of the brain while solving mental tasks. The Neuro Sky Mind WaveTM technology was used to record EEGs during the cold exposure in two subzero environments. Tsai-Partington test was used to stimulate the brain activity during the state of thermophysiological comfort and during the cold exposure. The results obtained showed differences in the type of the emitted brain waves and the total brain power used during the same activity in the cold.

1. Introduction

The human body has an extremely sophisticated thermoregulatory system that reacts to the temperature of the environment to keep the temperature of the internal organs around 37 °C. Without the protection of clothing and textile items, however, the thermoregulatory system could not cope with body protection at temperatures below 18 °C [1]: depending on the time of the exposition, metabolic and metabolism the low temperatures will lead to lighter or heavier cold-related health problems. Therefore, clothing is a significant factor for all human activities in the cold, being a protective barrier between the environment and the body and an active participant in the processes of heat and mass exchange between them [2, 3].

Despite the importance of the cold environment for the health, productivity and comfort of a substantial part of the population on earth, there are no standardized values of the required thermophysiological properties of low-temperature protective clothing for heat, air and moisture transfer [4]. An important reason for this is the interdependence of these properties as well as their dependence on the specific structural, geometric and mass characteristics of the textile articles and their combinations used in the garments [5]. The vast variety of options does not allow for standardized requirements [6]. Textiles and clothing, on the other hand, are only one aspect of thermophysiological comfort in a cold environment that cannot be considered in a complex way without an assessment of the environmental parameters (temperature, humidity, air velocity), metabolic activity and duration of exposure.
The thermophysiological reactions of the body in cold environment are initiated by the hypothalamus: the gland in the brain, which is responsible for constant comparison between the signals, coming from the blood, washing this part of the brain, and the signals, coming from the cold thermoreceptors in the skin. Therefore, the hypothesis that the brain waves measurement can give a piece of additional information on the processes inside the brain that control the thermoregulation of the human body, sounds logical.

The recorded electric potentials in the brain or electroencephalograms (EEGs) allow estimating the synaptic action related to behavior and cognition [7]. Thus, an EEG provides genuine “window on the mind,” at large scales [8].

Neuro Sky Mind WaveTM is state-of-the-art technology for a recording of brain waves, created in 2009 and subject to improvements over the 2012-2013 period [9]. It has been already in use in a series of research: for emotional responses [10], the assessment of the level of meditation [11], the connection between the brain activity and adult and child reading [12], and the performance of individuals [13].

This paper presents a pilot study on the human thermophysiological comfort in the cold indoor environment via non-invasive measurements of the brain weaves. A single point EEG was used to evaluate the brain activity in an artificial cold chamber with two subzero temperatures (-1 °C and -11 °C). The brain activity and brain power were measured during completion of a Tsai-Partington test and assessed in conditions of thermal comfort, at the begging and the end of the cold exposure. The results obtained showed the measurable effect of the cold environment on the power and the type of brain activity.

2. Protocol
The experiments were performed in an artificial cold chamber (3x2x2.20m) with two subzero air temperatures (-1 °C and -11 °C). The air temperature and relative humidity in the chamber were continuously recorded during the experiment. A clothing ensemble with insulation of 1.53 clo was used [5]. Hands and heads remained uncovered. During the exposure, a thermal infrared camera, model FLIR E6 (FLIR Systems Inc., Wilsonville, OR, US) was used for remote recording of the surface temperature of the body (clothed and uncovered).

The volunteers in the experiment were three young female subjects with the following data for their height, body mass, and age: 1.60 m (SD 0.006), 52.7 kg (SD 3.05), 29.6 years (SD 3.05). According to the questionnaires none of them had diseases that require systemic use of drugs, including hormonal pills. Neuro Sky Mind WaveTM [9] was used to record single point EEGs during the tests, performed in the cold. The device explored the electrical signals generated by brain activity. The sensor was placed on the forehead (with a textile strap). An additional sensor (part of the device) was attached to the ear for measuring the heart rate.

The study was performed in two phases: Phase one (ambient temperature of -11 °C), and Phase two (ambient temperature of -1 °C) organized 48 h after the first phase. The duration of the exposure was 30 ± 5 min. Before and after the exposure each participant rested in an air-conditioned laboratory (22 °C, 65% RH) for 65 ± 5 min.

Brain wave recording was done during the completion of the Tsai-Partington test [14], used to assess the level of "alertness" and the performance. It refers to the sequential connection of the numbers 1 to 30, randomly placed in the volume of sheet A4, as shown in Figure 1. The number 1 is in the center. and during the connection of the numbers, the pen should not be lifted from the sheet. The test and the brain waves recoding lasts 30 seconds.

3. Results and discussions
Figure 2 presents an exemplary picture and the corresponding thermogram of one of the volunteers during the cold exposure: Tsai-Partington test accomplishment with the Neuro Sky Mind WaveTM device on the head. The signals obtained during the brain wave recording related to the electrical
potential (potential energy) of the brain waves (µV^2) and the power, defined as energy per second (µV^2/s). The raw signal of the EEG was processed afterwards by additional software [13, 14].

![Figure 1. An exemplary pattern of the Tsai-Partington test](image)

![Figure 2. Tests and brain waves recording during the cold exposure: a) picture; b) thermogram.](image)

Brain waves of different frequencies that correspond to a variety type of activity of the cortex were measured. The correspondence between the type of the brain wave and the human physiological reactions are summarized as follows [13]:

- Delta brain waves: 0.5-2.75 Hz; appear in states of deep sleep (no dreams) and unconsciousness, associated with subconscious thoughts and information.
- Theta brain waves: 3.5-6.75 Hz; appear in states of mild sleep or creative activity, related to intuition, fantasy, imagination.
- Alpha brain waves - low and high frequency:
  - Low-frequency alpha (7.5-9.25 Hz); appear in tranquility in a conscious state.
  - High-frequency alpha waves (10-11.75 Hz); appear in waking states of relaxation.
- Beta brain waves - low and high frequency:
  - Low-frequency (13-16.75 Hz); appear in conditions of a motor and sensory rhythm, attention, tranquility but with the ability to concentrate.
  - High-frequency (18-29.75 Hz); appear in concentration or agitation.
- Gamma brain waves: 31-49.75 Hz; appear in states of high activity.
All types of brain waves occur simultaneously but with different amplitudes. The cumulative value of brain waves represents the total value of brain power.

3.1 Results from the acclimatization

The preliminary preparation for the cold exposure of the subjects includes acclimatization in an air-conditioned laboratory (22 °C, 65% RH). The participants solved a Tsai-Partington test. Figure 3 shows the EGG of Individual 1 in the two phases of the measurements.

The results obtained present short-time modulations about background levels, which is believed to be generated largely by synaptic action fields [7]. The analysis of the graphs shows that the total energy from the brain activity is determined mainly by the dominating delta waves. The same was found for the other two participants. This result coincides with the conclusions in [15-16]. The peaks appearing in Figure 3, as well as the following figures for solving the Tsai-Partington test correspond to finding a specific test digit. If the detection the next digit in the test was easier, a smaller amount of brain energy was consumed. For example, 13 peaks were recorded in Fig. 3a and the participant in the test succeeded to connect 13 consecutive numbers.

3.2 Results from the study in the cold environment

The Tsai-Partington test was completed twice: approx. 7 min and 21 min after the beginning of the cold exposure, conditionally considered as “at the beginning” and “at the end” of the exposure.

Figures 4-6 present the EGGs at the beginning and the end of the cold exposure of the three participants in Phase 1 (-11 °C; 1.53 clo). Unlike the reference EGGs in the acclimatization (a comfortable environment), both delta and theta waves brightly expressed, together with the appearance of alpha, beta and gamma waves.

To compare the results of Figures 4-6, the mean values of the total energy, emitted from the brain cortex of each participant during acclimatization (reference value) and at the beginning and the end of the cold exposure, were calculated. The results in Fig. 7 clearly show that the brain power during the Tsai-Partington test was lowest in thermal comfort conditions during the acclimatization. Solving the same test in the cold environment, Individual 1 increased with 32% her brain energy, Individual 2 – with 29%, and in Individual 3 – with 192%. It should be noted that the reference value of the total brain energy for Individual 3 had the lowest value during acclimatization.

The protective ability of the clothing ensemble during the cold exposure decreases with time. The sedentary position of the participants, performing the tests, inhibited the heat production due to muscles work. Therefore, the cold load increased with the length of the exposure, and for two of the participants, there was a difference in the total brain power at the beginning and the end of the stay in the cold.

The change in the mean value of the total brain power is most striking for Individual 2: at the end of the exposure, the test was performed at a 48% increment of the total brain power compared with the total brain power at the beginning of the exposure. For Individual 1, there was a decrement of 11%. For Individual 3 there was a slight increment of 1%.
Figure 4. Brain waves during cold exposure (-11 °C; 1.53 clo), Individual 1: a) beginning of exposure; b) end of exposure.

Figure 5. Brain waves during cold exposure (-11 °C; 1.53 clo), Individual 2: a) beginning of exposure; b) end of exposure.

Figure 6. Brain waves during cold exposure (-11 °C; 1.53 clo), Individual 3: a) beginning of exposure; b) end of exposure.

Figure 7. Mean total brain power during the acclimatization, at the beginning and at the end of the cold exposure (-11 °C, 1.53 clo)
4. Conclusion
As a result of the present study, it can be concluded that the cold environment influences brain activity and type of brain waves. The total brain power required to perform a particular mental task in a cold environment is higher than the energy needed to complete the same task in the conditions of thermophysiological comfort. Additional research is required in order to assess the effect of the duration of the exposure in the cold environment on the total brain power, especially in the direction of increasing the exposure interval and number of participants.

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