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Dynamic thermal imaging analysis in the effectiveness evaluation of warming and cooling formulations

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ABSTRACT

Warming cosmetics and medicines are used to accelerate recovery from injuries whereas cooling preparations are used in the pains of muscles, joints, spine, bruises or edema. The paper verifies subjective heating or warming sensations with respect to the measured temperature changes. The influence of three formulations, labelled C_1, C_2, W_1, on skin reaction was tested. The first two formulations (C_1, C_2) had a cooling effect while the formulation W_1 had warming properties. Two hundred thermal images with a resolution of $N \times M = 120 \times 120$ pixel were acquired with the Flir i7 infrared camera. The paper also shows how to analyse low resolution thermal images and their practical usefulness. For this purpose, a dedicated algorithm for image analysis and processing, which uses morphological operations, segmentation and area analysis, was applied. Application of both C_1 and C_2 resulted in subjective perception of feeling cold. Approximately 7 min following application of the formulation C_1, the skin temperature returned to baseline levels. The minimum skin temperature after using the formulation C_1 was 27.5 °C and it was registered at the time of application. Application of W_1, which by definition is a warming formulation, caused a sensation of coolness in the first minutes following the application. The perception of cool and warm sensations after the application of topical formulations is in no way correlated with the skin temperature assessed using a thermal imaging method.

1. Introduction

Warming topical preparations are traditionally used in muscle, joint and nerve pain. Warming substances due to their vasodilator action cause local congestion. Therefore they can be used as permeation promoters. Warming cosmetics and medicines are sometimes used to speed recovery from injuries. Cooling preparations are used in muscle, joint or spine pain, bruises, edema as well as to reduce the effect of "heavy legs" [1]. The substances most often used as warming agents are: capsaicin, camphor and methyl nicotinate. In contrast, menthol, ethyl alcohol and isopropyl alcohol are used as cooling agents [1,2].

It is extereceptors that are responsible for the feeling of warmth or coolness—kind of a superficial sensation received by skin receptors [3]. Feeling temperature is perceived by thermoreceptors present at the ends of small myelinated fibres (Aδ) and fibres without myelin sheath (C). Feeling warm or cool sensations is possible owing to separate receptors with separate receptive fields. The fibres that transmit a sensation of coolness temporarily increase the frequency of impulses, and thus intensify the perception of feeling cold when the skin temperature decreases, and temporarily reduce the frequency when the skin temperature increases. Thus, a rapid drop in temperature is subjectively perceived as an intense stimulus, regardless of the amplitude of temperature drop/rise. In the ambient temperature and neutral zone (thermal comfort), there is complete perceptual adaptation (temperature sensation disappears). Warm and cold receptors sense a temperature drop or rise only when the ambient temperature differs from the temperature of the skin surface. Given the same skin surface temperature and ambient temperature, the receptors are not activated. This condition is called physiological zero. Cold receptors (called Krause's end bulbs), whose number is 10 times bigger than that of the warm receptors, sense temperature in a wider range (15 ± 35 °C) than warm receptors (referred to as Rufini corpuscles) which are responsive in the range of 35 ± 43 °C [4,5]. Feeling cold and warmth takes place only when the temperature change concerns receptors and occurs quickly

Abbreviations: ROI, region of interest

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enough. The threshold stimulus for cold receptors is the skin temperature drop of 0.004 °C/s in the range from 10 to 41 °C, whereas for warm receptors it is an increase in the skin temperature of 0.001 °C/s in the range from 20 to 45 °C [4]. Conduction of nerve impulses responsible for cold and warm sensations is possible owing to the presence of various types of ion channels within the warm and cold receptors. Thermoreceptors belong to the group of thermosensitive channels *Transient Receptor Potential* (TRP) for which seven different subfamilies have been identified: *Transient Receptor Potential Cation* (TRPC), *Transient Receptor Potential Vanilloid* (TRPV), *Transient Receptor Potential Ion—Melastatin* (TRPM), *Transient Receptor Potential Ion—mechanical stress sensor* (TRPA), *Transient Receptor Potential Polycystic* (TRPP), *Transient Receptor Potential Cation* (TRPML) and *Transient Receptor Potential—mechanoreception* (TRPN) [6]. Six of them are responsible for the perception of thermal stimuli in mammals, including humans [6,7]. In summary, by means of chemical stimuli – substances contained in cosmetics or medicines – it is possible to cause subjective feelings of coolness or warmth [6–9].

One of the most important factors controlling the skin surface temperature is the blood flow within the skin microcirculation. About 90% of the skin flow is responsible for thermoregulation during a game, and only about 10% is responsible for the metabolic needs of the skin [10]. At rest, without the participation of chemical and physical stimuli, the blood flow is approximately 5% of the cardiac output and 25% of blood vessels are active [10,11]. The blood flow in the skin vascular bed depends on the vascular tone, which is controlled by local autoregulation, neurogenic stimulation and humoral factors [10,12]. It is also possible to control – increase or decrease – the blood flow by skin vessels using chemical agents: blood vessel dilators, vasodilators, and blood vessel constrictors, vasoconstrictors. Cosmetic ingredients acting as vasodilators are, inter alia, methyl nicotinate, ethyl nicotinate and others [13]. Another mechanism of action, which changes the skin temperature by affecting the skin vascular bed, is reaction of substances whose rapid evaporation from the skin lowers its temperature. Such a method, with the use of, inter alia, isopropyl and ethyl alcohol, was used to treat hyperthermia [14]. Currently, ethyl alcohol is no longer used in the treatment of hyperthermia but is sometimes used in cooling topical formulations. However, the use of ethanol in the skin care cosmetics is limited because of its drying action [15].

The analysis of thermal images only in some areas is consistent with the analysis of images in visible light. It is difficult to work and interpret results for virtually every operation of image analysis and processing. There are problems with separation, segmentation of objects with very little temperature differences. There are problems with sharpening the edges due to their natural blur—convection of temperature to the ambient temperature in the case of objects warmer than the room. In the case of tests conducted on patients, there is a problem with their individual impact on the results, e.g. warm meals consumed before the test, obtaining thermal comfort in the room, undisclosed illnesses, contact of the measured area of the body with extraneous objects causing a local increase in temperature, etc. [16–18]. Also test implementation itself can cause later problems with automatic data analysis. For example, in all the places where one skin area touches another one, such as inner thighs, there is a problem with edge detection [19,20]. This causes considerable problems with segmentation which do not occur, or occur to a lesser extent, in visible light. The only practically important element in which segmentation of thermal images brings better results than that of images taken in visible light are areas with temperature differences. The temperature difference allows for not only segmentation of areas not visible in visible light but also enables to carry out almost perfect binarization [22]. Perfect binarization here means separation of an object from the background without artefacts and holes in the object—typical for image thresholding in visible light or another type of imaging [23,24]. Fully automatic measurement and data analysis, without an operator, are only possible when the algorithm for image analysis and processing is profiled [25–27].

The analysis of thermal images can be divided independently into static and dynamic one. In the case of static analysis, absolute temperature changes of a given area of the human body are recognized. These values are mostly average temperatures in the region of interest (ROI), a minimum or maximum value. Dynamic analysis enables to observe temperature changes in response to a specified force applied in the ROI. It is then possible to identify the object, in this case a human, as a measurement of time constants τ or delays in temperature changes. Dynamic analysis can also be used here to assess the impact of cooling or warming preparations, which is presented in this paper.

2. Material

The paper studied the influence of three formulations, labelled C_1, C_2, W_1, on the skin reaction. The first two formulations (C_1, C_2) had a cooling effect while W_1 had warming properties. The composition of formulations was as follows:

C_1: alcohol denta., propane/butene/isobutane, aqua, menthol, glycerin, aesculus hippocastanum extract, arnica montana extract, calendulae officinalis extract, glucosyl hesperidini, panthnol, propylene glycol, PEG-40, hydroenated castor oil, parfum, hexyl cinnamal, limonene, linalol, geraniol, citronellol. Active ingredients: menthol 2.1%, ethyl alcohol 42%.

C_2: butane, aqua, isobutene, propane, alcohol denat., cyclopentasioxane, cyclohexasiloxane, PPg-5 ceteth-20, glycerin, hydroxyetylocellulose, PEG-40, hydrogenated castor oil, parfum, rucus aculeatus root extract, citrus limon peel extract, solidago virgaurea extract, phenoxyethanol, benzoic acid, dehydroacetic acid, benzyl salicylate, buthylphenyl methylpropional, linalool, hexyl cinnamal, geraniol. Active ingredient: ethyl alcohol 4.7%.

W_1: cyclopentasiloxane, propane/butane/isobutene, alcohol. Denat., diethylhexyl carbonate, isopropyl myristate, dipropylene glycol, boswellia serrate gum, methyl nicotinate. Active ingredient: methyl nicotinate 0.55%.

Two hundred thermal images were acquired with the Flir i7 infrared camera. These have the following parameters: thermal sensitivity of <100 m K, field of view—$25^\circ \times 25^\circ$, spectral range from 7.5 to 13 μm. This provided a sequence of images $L_{GRAY}(m,n)$ with a resolution of $N \times M = 120 \times 120$ pixel. The objects of imaging were patients with manually applied formulations C_1, C_2 or W_1. In total, one image sequence was acquired for 3 patients. The measurements were performed at room temperature of 24.4 °C and relative humidity of 39.9%. The patients before measurements were acclimatized to room conditions for at least 20 min. The measurement conditions were minimized: a lack of infrared sources in the test room, errors related to damping, scattering and emission of own atmosphere, errors arising from the registration of radiation reflected from the object, convection of air currents, patient's emotional state and movements during data acquisition. A block diagram of the test procedure is shown in Fig. 1. On the right hand side of the image there is a typical graph of changes in temperature caused by application of a formulation cooler than skin and the dynamics of temperature changes over time. It also shows the response of the object (patient) to force in the form of a cooler formulation and time constant τ.

The thermogram acquisition was performed according to the following scheme:

For C_1: before application, immediately after application (about 2 s), and then every 1 min for another 12 min.