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Sensitivity to cutaneous warm stimuli varies greatly in the human head

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ABSTRACT

The head has been known as the most sensitive area to temperature changes but the values are limited to the face. The purpose of this study was to examine cutaneous warm thresholds on the scalp and face of young males. Eight males participated in this study (24 ± 3 yrs in age, 178.2 ± 5.3 cm in height, and 90.0 ± 15.4 kg in body mass). All measurements were conducted in an environmental chamber (27 ± 1 °C air temperature and 53 ± 1% relative humidity). Cutaneous warm thresholds were measured on nine areas of the following regions: the frontal (two points on the right), parietal (a point on the right and the vertex, respectively), temporal (two points on the right), and occipital region (on the right) along with the forehead using a thermal stimulator (rate of temperature increase 0.1 $^{\circ}C\,s^{-1}$). Skin temperatures on the nine head regions were monitored during the threshold test. The results showed that 1) no significant differences were found in initial skin temperatures among the nine head regions; 2) cutaneous warm detecting temperatures were significantly greater on the vertex (38.2 ± 3.5 °C) than on the forehead (34.8 ± 1.4 °C) and the other seven scalp regions ($P < 0.05$); 3) subjects detected the increase of 1.2 ± 1.0 °C on the forehead and 1.5 ± 1.2 °C on the occipital region as the first warmth while the vertex was the most insensitive to the increase of temperature (4.0 ± 3.2 °C) ($P < 0.05$). In summary, the scalp region of young males was less sensitive to the temperature change when compared to the forehead, and the vertex was the most insensitive among the eight scalp regions to the temperature increase. We conclude that the entire head should be considered as a binary topography with the face and the scalp in terms of cutaneous thermal sensitivity.

1. Introduction

Cutaneous thermal sensation involves peripheral sensory nerves that innervated in the skin and plays an important role in thermoregulation during heat and cold stress. The nerves enter the central nervous system in the superficial dorsal horn of the spinal cord and end in the thalamus and somatosensory cortex where consciousness determines what kind of thermal stimuli is occurring on the skin surface (Feng, 2014). Such thermal afferent signals trigger thermoregulatory behaviors as well as vascular and sweating responses during heat stress or metabolic and shivering responses during cold stress. The process from detecting warmth or coldness in the skin to the initiation of thermoregulatory behavior can be briefly summarized in the following paragraph.

Sensory nerves densely innervate in the skin and directly sense temperature changes in the skin (Dhaka et al., 2006). Temperature changes in the skin cause neuronal depolarization through activation of excitatory receptor channels (temperature receptors). Transient receptor potential (TRP) ion channels are expressed in the cutaneous nerve endings of primary afferents and respond to distinct thermal thresholds. Because this study is limited to cutaneous warm sensitivity, we refer to warm sensitivity under heat stress. Temperatures above 33 °C activate the TRPV3 ion channel (Schepers and Ringkamp, 2009), which has a heat threshold below 39 °C and continues to respond to temperatures beyond the heat pain threshold (48–50 °C) (Green, 2004). That is, TRPV3 is capable of responding to both innocuous and noxious heat. TRPV4 alone accounts for the sensitivity to innocuous warming below 40 °C (Green, 2004). TRPV4 was discovered in skin keratinocytes rather than in neural tissue and TRPV3 is also expressed in keratinocytes as well as in other tissue including dorsal root ganglia (DRG) neurons (Green, 2004). TRPV3 and TRPV4 in keratinocytes have raised the possibility that skin epithelial cells can mediate the perception of warm temperatures directly (Dhaka et al., 2006). Neurons in the DRG and trigeminal ganglia extend dendrites just below the skin and function in the detection of external temperature (Montell and Caterina, 2007). The preoptic/anterior hypothalamus (POAH) in the brain is both a direct sensor of local temperature and an integrator of thermal input from peripheral neurons (Montell and Caterina, 2007). Finally, signals

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emanating from the POAH drive both physiological and behavioral responses to an undesirable temperature.

However, the sensitivity to warmth varies across the body and within dermatomes in healthy subjects. Cutaneous warm thresholds on body regions including the forehead have been reported showing the greatest sensitivity of the head and the least sensitivity of the lower leg (Lee et al., 2010). The importance of the head in driving physiological and behavioral responses is well recognized in dissipating a great deal of heat under hot conditions (Desruelle and Candas, 2000) as well as the greatest thermal sensitivity. Cutaneous vasodilation and skin blood flow in heat was more pronounced in the head than in other body regions (Inoue and Shibasaki, 1996). Sweating rates and active sweat glands were greater for the head than for the trunk or arms (Randall, 1946). Emphasizing the scalp's importance in this respect is the finding that cooling the head (including the scalp) is particularly effective in alleviating heat strain and maintaining thermal comfort during heat exposure (Desruelle and Candas, 2000; Shvartz, 1970). Despite its small surface area (7% of body surface area; Lee and Choi, 2009), cooling the head can elicit significant reductions in thermal strain (Nunneley et al., 1982; Shin et al., 2015). In addition, the hypothalamus, which is the thermoregulatory center, is located in the middle of the brain (Fauci et al., 2008).

Although a couple of reports exist detailing the cutaneous thermal sensitivity over the surface of the body including the head, the studies have not investigated the entire head, but rather the forehead or face was chosen as a representative region for the head (Lee et al., 2010). The little data available for the scalp suggests that thermal sensitivity is relatively poor on the vertex compared with the face and forearm (Essick et al., 2004). Therefore, we should not assume that values on the forehead or face adequately represent the entire head. The difference in thermal sensitivity between the face and the scalp would be related to the anatomical differences. Face skin is innervated by the trigeminal ganglion. Scalp skin has a complex neural network, innervated by trigeminal and cervical nerves, that contain densely innervated hair follicles and a well-organized network of highly innervated vasculature with abundant small nerve fibers (Saif et al., 2012). Therefore, the scalp can be expected to be extremely sensitive to small changes in C nerve fiber-mediated sensations such as warmth. However, Saif et al. (2012) reported greater warmth and heat pain thresholds on the scalp (the crown and occiput) than the forearm. A majority (64%) of the crown warmth threshold measurements exceeded 50 °C, while no one reported warmth thresholds over 50 °C on the forearm (Warm thresholds: 34.5 ± 1.4 on the forearm, 42.9 ± 4.2 on the occiput, and 47.6 ± 4.1 °C on the crown). Their study demonstrates a significant insensitivity of C nerve fibers of the scalp to warmth and suggests that the scalp has an aberrant response of C nerve fibers.

Although Essick et al. (2004) and Saif et al. (2012) reported on the insensitivity of the scalp to warm stimuli, very limited data are available on the detailed distribution in thermal sensitivity by region of the scalp. Such limited data on the scalp, which is due to the hair, is a particularly important gap for understanding the cutaneous thermal sensitivity in the entire body. The purpose of this study was to investigate cutaneous warm sensitivities on the face and scalp area in shaved young male subjects. The hypothesis was that the vertex would be the least sensitive to warmth, while the forehead and the occiput would be more sensitive to warmth than other regions on the head. Findings from this study will contribute to our understanding of physiological and behavioral thermoregulation in general and topography of cutaneous sensitivity on the head in particular. We expect that this study would help to make physiologically-designed headgear which would be more effective for alleviating heat strain and accelerating heat loss from the head of workers in heat.

2. Methods

2.1. Subjects

Eight young males (24 ± 3 yr in age, 178.2 ± 5.3 cm in height, and 90.0 ± 15.4 kg in body mass) participated in this study. None of the eight male subjects were naturally bald. Subjects abstained from alcohol, smoking and strenuous exercise for the previous 24 h and were prohibited from taking any food for 2 h prior to their scheduled tests. All were free of neurological illness and without any medical condition that may cause peripheral neuropathy. All subjects attended a familiarization trial prior to the main experiment. Informed consent was obtained from all subjects in advance. The experimental protocol was approved by the Institutional Review Board of Seoul National University (IRB No. 1608/003-023).

2.2. Experimental design and procedure

All subjects shaved their whole head before participating. Experiments were conducted in a climatic chamber that maintained an air temperature of 27 ± 1 °C and 53 ± 3% relative humidity and at the same time of day. Upon arriving, subjects drank 300 ml of water to prevent from being thirsty during experiments. Subjects wore short t-shirts, undershorts and short pants to maintain thermal neutrality during the experiment at the climatic chamber. After entering the climatic chamber, subjects spent about 30 min sitting on a chair to stabilize their body. After stabilization, we drew lines on the head using a water-based pen to divide measuring regions (Fig. 1). Cutaneous warm thresholds were measured on the following nine head regions: the frontal (two points on the right, P1 and P2), temporal (two points on the right, P3 and P4), parietal (the vertex, P5 and two points on the right, P6 and P7), occipital region (on the right, P8) and the forehead (P9) (Fig. 1). All measurements were done on the right side of the head excluding P5, P8 and P9. During the experiment, subjects were comfortably seated on a chair. We repeated a set of the measurement [P1 to

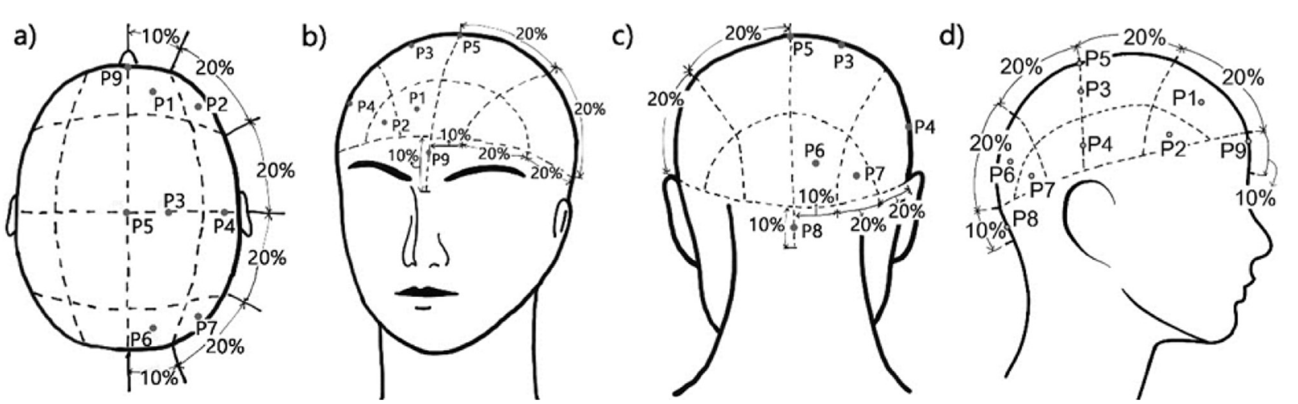

Fig. 1. Dividing the surface of the scalp and nine measuring points from P1 to P9. (a) top view, (b) front-diagonal view, (c) back view, and (d) side view.