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Effect of thermal sensation on emotional responses as measured through brain waves

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A B S T R A C T

Beyond previous research topics assessing physiological or psychological effects of an indoor environment, the present study aims to investigate the effect of thermal sensations on people's emotional responses. For achieving this purpose, chamber experiments were conducted based on three different temperatures (PMV −2, 0, +2), and results were obtained from 139 participants' brain wave data. The emotional process depending on indoor temperature was not significant; however, that depending on subjective thermal sensations were statistically significant. Since participants felt same indoor thermal condition differently, the physical indoor temperature itself had no direct significant influence to their emotions. Positivity bias was observed when participants felt neutral and slightly warm, and negativity bias was observed in all other cases. This study supports the notion that the thermal environment affects occupants' emotional responses through subjective thermal sensations.

1. Introduction

In today's society, people are spending increasing time indoors. Therefore, the indoor environment quality has attracted much research interest. Many studies have focused on thermal comfort in terms of the conditions for occupants' comfort or its effects on health or productivity.

According to the adaptive theory, it can be said that comfortable indoor conditions can be changed by psychological adaptations through their effects to thermal sensation [1]. This psychological adaptation cannot be easily measured directly and quantified. Therefore it is usually mentioned as an altered perception of, and reaction to, sensory information due to subjective past thermal experiences and expectations.

Psychological dimension of adaptation may be particularly important in context where people's interactions with the environment (i.e. personal thermal control) [2]. Some researches realized that the expectation according to the variation of personal control affects the thermal response [3,4]. Langevin found a statistically significant correlation between perceived control level of thermal environment and thermal comfort response using ASHRAE RP-884 database [5]. Moreover, there is a research that explored comfort expectations can be changed as a result of long-term exposure to another climate [6].

Psychological adaptation was researched in urban scale also. Nikolopoulou investigated thermal comfort conditions in outdoor urban spaces, and revealed that although microclimatic parameters strongly influence thermal sensation, they cannot fully account for the wide variation between objective and subjective comfort evaluation, whereas, psychological adaptation seems to becoming increasingly important [7].

There is a research that used the construct thermo-specific self-efficacy (specSE) to analyze differences in the perception of thermal comfort, assumed temperature, perceived control and physiological parameters. Data from field studies in office buildings were compared with data from laboratory experiments. Results showed an influence of specSE on thermal comfort, e.g. people with a low level of specSE feel warmer than people with high specSE [8].

However, there was no research which investigated the relationship between emotion and thermal sensation in context of psychological adaptation in thermal comfort.

Meanwhile, several studies have conducted on the relation

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between people's emotions and their thermal environment in Psychology research field [9–11]. However, these studies have been conducted on psychology and not on thermal comfort field, merely considering temperature control. In particular, no studies have considered the thermal environmental factors such as indoor temperature, relative humidity, air movement, and radiant temperature which is basic in the indoor environmental quality research field.

Emotions cannot be investigated through a single word or research method. To compensate for this difficulty, research methods have been developed for measuring the expression accompanying positive or negative emotions in response to positive or negative stimuli [12–14]. The present study holds that on the basis of physiological theories, emotion is considered as a mechanism arising from somatic responses and neural and biochemical changes [15]. Moreover, because emotion is a research field in neuroscience, approaches have also been established for measuring the intensity of an emotional expression by measuring brain waves during emotional expressions [16–20]. Therefore, in the present study, the event-related potentials (ERPs) method which is one of analyzing methods for brain wave is used to measure human emotion. Consequently, in this study, human emotion is viewed as an action taking place in the brain as a result of an elicitor.

On this background, the present study aims to investigate the effect of indoor temperature on occupants' emotion in the context of psychological adaptation for thermal comfort. This research also realized a synergistic effect by integrating the areas of indoor environmental quality and Psychology by exploiting the strengths of each area. To investigate the effect of indoor temperature on occupants' emotion, the present study measured occupants' subjective thermal sensations and emotional responses according to the temperature conditions in a climate chamber using brain waves. Through emotional arousal elicited by an emotional stimulus, it can be analyzed the relationship between thermal environment and emotion. Furthermore, the results of this study may be used to find indoor thermal conditions to induce positive emotions.

2. Materials and methods

2.1. Participants

The present experiment was performed with the permission of the Yonsei University Institutional Review Board (IRB), and it included 141 (male: 71; female: 70) physically and mentally healthy adult participants aged 20–29 years. The people excluded from the experiment were those with a history of neuropsychiatric disease, including attention deficit disorder, brain damage, epilepsy, and alcohol addiction, as well as people taking medication for a psychological disorder and those with corrected eyesight of less than 0.5. All of the participants were asked not to stay awake late at night or drink too much on the day before the experiment. They were randomly divided into three groups for three experimental conditions (cold, neutral, and hot). The participants' characteristics are shown in Table 1.

Table 1
Characteristics of participants.

Age	Height (cm)	Weight (kg)	BMI (kg/m^2)
24.19 ± 1.07	167.91 ± 4.45	61.39 ± 5.42	21.60 ± 1.05

2.2. Experimental conditions

To examine the differences in responses to positive and negative emotional stimuli (pleasant and unpleasant pictures) according to the subjective thermal sensation, the present study measured event-related potentials (ERPs) in a low-temperature “cold” environment (17.8 °C, PMV −2), a high-temperature “hot” environment (30.8 °C, PMV +2), and a mild temperature “neutral” environment (24.4 °C, PMV 0). These three conditions were determined according to Fanger's Predicted Mean Vote (PMV). The radiant temperature was assumed to be the same as the air temperature in this study, because the experimental chamber was located in a building and was free from direct sunlight. Thermal environmental elements other than air temperature were controlled (Tables 2 and 3).

2.3. Measurement tool—Event-related potential (ERP)

By measuring brain activity from the scalp in real time, an event-related potential (ERP) allows the observation of brain responses elicited by a specific incident over a certain period of time [13]. The most notable characteristic of emotion is that its time course is rapid and relatively automatic [21]. Moreover, the perception of an affective stimulus and affective evaluation occur automatically, even in the absence of conscious awareness [12]. Accordingly, to capture rapidly occurring affective processing, it is advantageous to use ERP methods given their excellent temporal resolution capabilities [22].

The ERP is obtained by averaging the brain waves that occur across multiple trials within a specific time after stimulus presentation. The resulting ERP waveform comprises several peaks. The ERP components are defined on the basis of these peaks, and each component is analyzed separately [23]. Late positive potential (LPP) is an ERP component that develops in a more positive direction for affective than neutral pictures from around 300 ms (ms) after stimulus onset at centro-parietal sites [24]. The LPP is elicited by presenting an affective stimulus, and when a pleasant or unpleasant stimulus is presented (compared to a neutral stimulus), the LPP shows larger amplitude [20,21,25,26].

The ERP was recorded using Ag/AgCl electrodes from eight scalp locations based on the international 10–20 system [27] using an electrode cap (Electro-Cap International, Inc., Eaton, OH, USA). On the basis of a functional classification of the brain, eight locations were selected corresponding to the pre-frontal lobe, frontal lobe, temporal lobe, and parietal lobe (the occipital lobe, which is responsible for visual functions, was not included). The right earlobe served as a reference. The recording locations included four lateral sites to the left of the midline (Fp1, F3, T3, and P3) and their

Table 2
Controlled thermal environmental condition of the chamber.

Relative humidity	Air speed	Metabolism	Clothing
50%	≤0.1 m/s	1.0 met	0.8 clo

Table 3
Experimental condition of the chamber.

Condition	Air temperature (°C)		Relative humidity (%)	
	Set	Actual	Set	Actual
Cold (PMV −2)	17.8	17.80 ± 0.04	50.0	50.23 ± 0.30
Neutral (PMV 0)	24.4	24.25 ± 0.24	50.0	50.06 ± 0.34
Hot (PMV +2)	30.8	30.80 ± 0.05	50.0	50.01 ± 0.54