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

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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

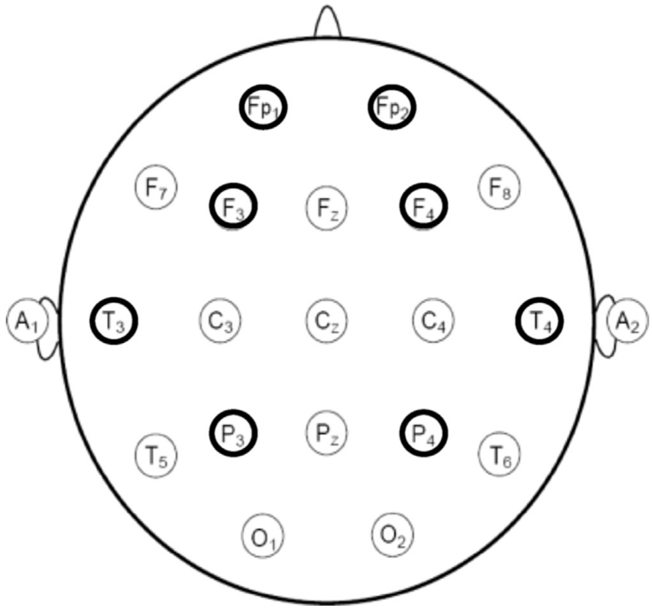

Fig. 1. International 10–20 system of electrode placement [27].

homologous sites to the right of the midline, as shown in Fig. 1.

An electrooculogram (EOG) was recorded to remove artifacts including blinks and eye movements using disposable surface electrodes (Tyco Healthcare Group LP, Norwalk, CT, USA). A 0.01–30 Hz band-pass filter was used for all electrophysiological recordings. The ERP and EOG were amplified using an MP150 bio-signal instrumentation system (Biopac Systems Inc., Santa Barbara, CA, USA). In addition, the ERP and EOG were sampled at 1000 Hz for 2100 ms, starting 200 ms before the presentation of the stimuli and ending 1900 ms afterwards.

2.4. Stimuli and experimental protocol

The present study used International Affective Picture System (IAPS) pictures as emotional stimuli for presentation within an oddball paradigm.

The IAPS is often used for visual stimuli in emotion research. This database comprises over 956 pictures depicting various emotional situations, and each picture has been rated according to valence and arousal [25]. Valence and arousal are rated on a nine-point scale, with higher valence scores indicating greater pleasantness evaluations and lower valence scores indicating greater unpleasantness evaluations. Higher arousal scores indicate higher levels of arousal and lower arousal scores indicate lower levels of arousal. The Center for the Study of Emotion and Attention at the University of Florida standardized this picture system. The use of pictures with the appropriate level of valence and arousal based on the study's experimental protocol aims to give these stimuli the advantage of effective control, reproducibility, and comparability with other experiments that use IAPS [28].

The pleasant pictures used for positive emotional (pleasant) stimuli in this study consisted of 100 images with a valence score greater than 7.03; these were taken from among high-valence IAPS stimuli. The unpleasant pictures used for negative emotional (unpleasant) stimuli consisted of 100 pictures with a valence score between 2.35 and 3.95, with 50 low-valence pictures that may cause the most psychological discomfort being excluded. Non-emotion eliciting patterns that represent neutral stimuli in this study were extracted from the “shutterstock” website (search engine for images, videos, and music: http://www.shutterstock.com/ [29]; last accessed on 3rd Feb 2017.). Examples of pleasant pictures, unpleasant pictures, and non-emotion-eliciting patterns used as control stimuli are shown in Fig. 2.

Several studies dealing with processing emotional stimuli have used an oddball paradigm to present these stimuli. The oddball paradigm is a method by which a stimulus with low presentation probability is presented between stimuli with high presentation probability [28]. During emotional stimuli oddball tasks, a neutral stimulus is commonly used as the standard stimulus, and an emotional stimulus is used as the target stimulus. Here, the target stimulus presentation probability is usually engineered to be below 30% [28]. These studies report that emotional stimuli consistently elicit greater P300 amplitudes [30–32] or late positive potentials [33,34] compared to neutral stimuli.

2.5. Experimental procedure

To maintain an identical thermal state across the participants, who were all to be exposed to a different environment, it was necessary for the participants to wait for 20 min in the pre-conditioning chamber while wearing the experimental uniform. The pre-conditioning chamber was controlled at an indoor temperature of 24.4 °C and relative humidity of 50% for PMV 0. During this waiting time, the participants were informed about the

Fig. 2. Example of stimuli (pleasant and unpleasant pictures, and non-emotion eliciting patterns in a separate row).

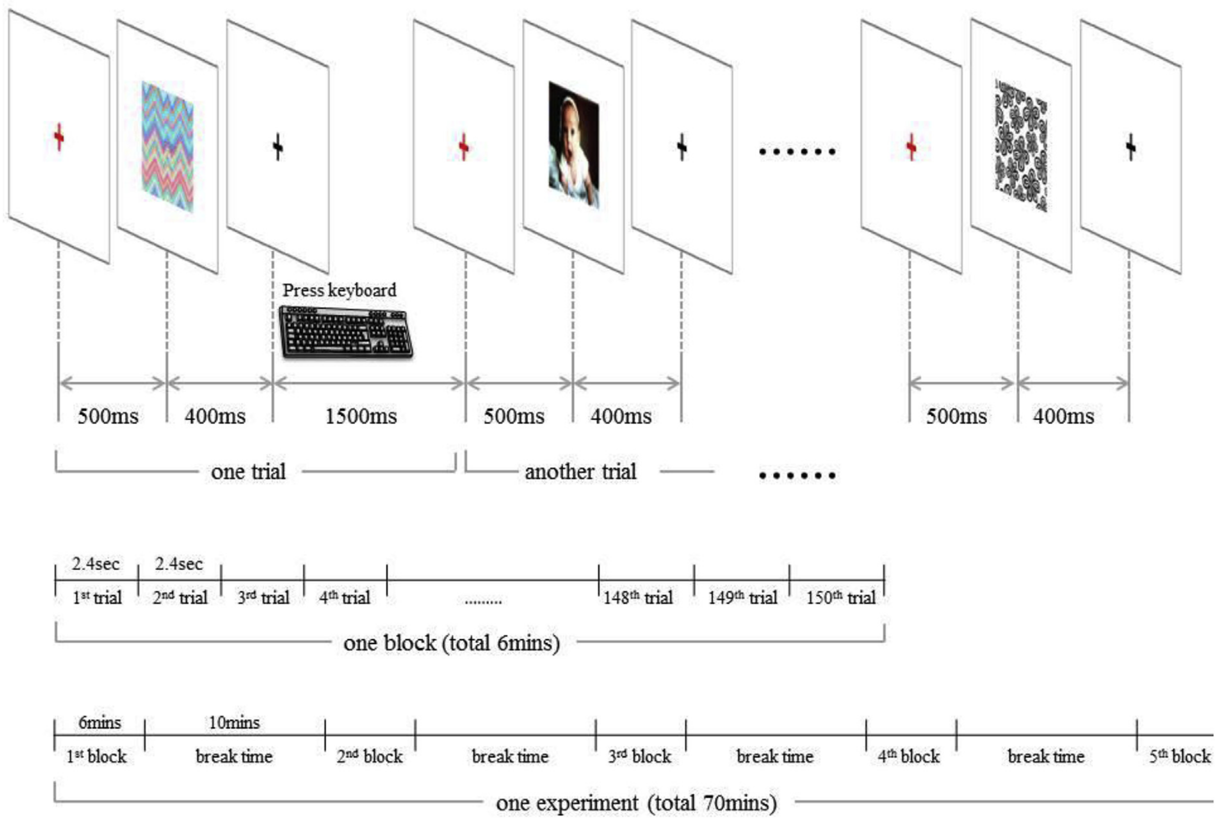

Fig. 3. Protocol of stimulus presentation.

experiment taking place in the main chamber, and after putting on the experimental uniform, they took part in a practice test that was performed as two blocks of 25 trials using the same protocol as the experiment itself. Brain wave and electrooculogram (EOG) electrodes were then affixed to the participants. After entering the climate chamber, they were exposed to the experimental environment for 70 min, during which time they performed a given task of distinguishing a type of emotion a total of five times each.

In this study, the participants performed an oddball task with the stimuli presented using the SuperLab 4.5 (Cedrus, San Pedro, CA, USA) program on a computer monitor. Usually, one task consists of several blocks. A "block" refers to a collection of some trials, and a single trial refers to a single stimulus presentation. In the present experiment, a single block consisted of 150 trials presented for 6 min. Of these, 50 were target stimuli (25 pleasant and 25 unpleasant pictures) and 100 were standard stimuli (patterns that do not elicit emotion). All stimuli were presented in a random sequence to all participants. At the end of each block, they recorded their subjective thermal sensations using ASHRAE's 7-point scale. To prevent eye fatigue, the participants were given 10-min breaks between blocks. Participants were instructed that if they judged the picture presented as eliciting either pleasant or unpleasant emotions, they were asked to respond by pressing "z" or "/" on the keyboard. They were also told not to respond to stimuli that did not elicit any emotion. The stimulus presentation protocol is shown in Fig. 3. One trial consists of three steps. A red cross appears on a monitor for 500 ms as a cue for the presentation of a stimulus. Then, a stimulus (emotional picture or a pattern that does not elicit emotion) is presented for 400 ms. Finally, a black cross appears as a cue for pressing the keyboard.

2.6. Analysis methods

To ensure a pre-recording time of 200 ms before stimulus onset as a baseline, event-related potential (ERP) data were recorded from 200 ms before to 1,900 ms after stimulus presentation. Thus, the analysis involved a total recording time of 2,100 ms. Artifact removal and filtering was performed using the AcqKnowledge 4.1 (Biopac System Inc., Santa Barbara, CA, USA) program prior to analysis. Ocular artifacts in the raw brain wave data were corrected according to a procedure developed by Ref. [35]. For all the remaining data, ERP waveforms were obtained by averaging trials in which the participants responded to the test stimulus regardless of correctness. Owing to cases where brain wave data were not recorded properly, indoor temperature was not perfectly controlled, or when poor electrode contact resulted in lack of a normal signal, the data from 2 people out of 141 were excluded from further analyses.

For the present study, analysis was performed using a late positive potential (LPP) time window set between 300 and 600 ms after stimulus presentation. For analyzing ERPs emerging at the frontal sites, the brain wave data were recorded from channels Fp1, Fp2, F3, and F4. Then, for analyzing ERPs emerging at the temporal sites, the brain wave data were recorded from channels T3 and T4, for those at parietal sites, from channels P3 and P4. Each site was described in the 10–20 system.

To investigate the effect of indoor temperature or subjective thermal sensation and valence on emotional processing (using ERP), a two-way repeated-measure ANOVA was performed using the emotional pictures (pleasant or unpleasant), indoor temperature, and subjective thermal sensations an independent variable

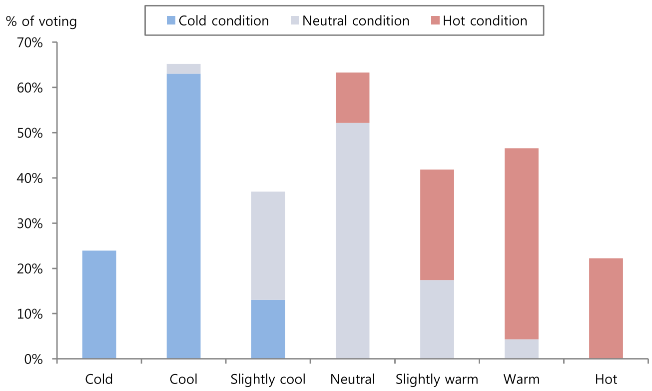

Fig. 4. Subjective thermal sensation vote in each indoor temperature condition.

and the mean amplitude of the LPP as a dependent variable.

3. Results

The present study captures emotion as brain waves emerging from emotion-elicited stimuli and measures these waves as event-related potentials (ERPs) from frontal, temporal, and parietal sites. The ERP components were investigated across the temperature conditions (cold: 17.8 °C, neutral: 24.4 °C, hot: 30.8 °C) based on the type of emotion-eliciting stimulus involved. Each participant experienced one of three experimental conditions. Of the 141 participants who took part in the experiment, indoor temperature was not properly controlled or brain wave data was not be properly recorded in the case of 2 participants. The remaining 139 participants were included in all analyses. From the visual inspection result, ERPs measured on frontal sites did not elicit brain waves by the presented stimuli because the effect of eye blinks remained despite its removal; therefore, these were excluded from the analysis. Only statistically significant results are described in this study. Therefore, only results of ERPs emerging from the parietal sites were reported.

3.1. Indoor temperature and subjective thermal sensation

Fig. 4 shows participants' responses to subjective thermal sensations in three different temperature conditions. While 87% of participants who experienced cold conditions answered that they felt cold or cool, the responses of those who were in neutral conditions varied from cool to warm. Furthermore, only 64% of participants who experienced hot conditions answered that they felt warm or hot.

3.2. Grand-averaged ERPs

Fig. 5 shows the grand averaged event-related potentials (ERPs) at the parietal sites according to the indoor temperature and presentation of pleasant, unpleasant, or non-emotion pictures.

The graph shows positive rising waveforms at around 250 ms after stimulus onset that peak at 350 ms. According to the late positive potential (LPP) time window (300–600 ms) defined in the present study, larger LPPs were observed when a pleasant and unpleasant picture was presented than when a non-emotional picture was presented.

3.3. Indoor temperature and emotion

Table 4 shows the results of the two-way indoor temperature × emotion repeated-measure ANOVA, which examined the differences in the late positive potentials (LPPs) elicited across the parietal site event-related potentials (ERPs) upon presentation of pleasant, unpleasant, or non-emotional pictures in various indoor temperature environments. There was a significant main effect of indoor temperature ($F(2, 273) = 4.09$, $p < 0.05$) and emotion ($F(2, 272) = 25.35$, $p < 0.001$). However, the interaction between indoor temperature and emotion ($F(4, 546) = 1.39$, $p > 0.05$) was not statistically significant, suggesting that emotional processing differed with valence regardless of the indoor temperature and suggesting that arousal differed with indoor temperature regardless of the emotion type.

3.4. Subjective thermal sensation and emotion

Fig. 6 shows the late positive potential (LPP) observed at parietal

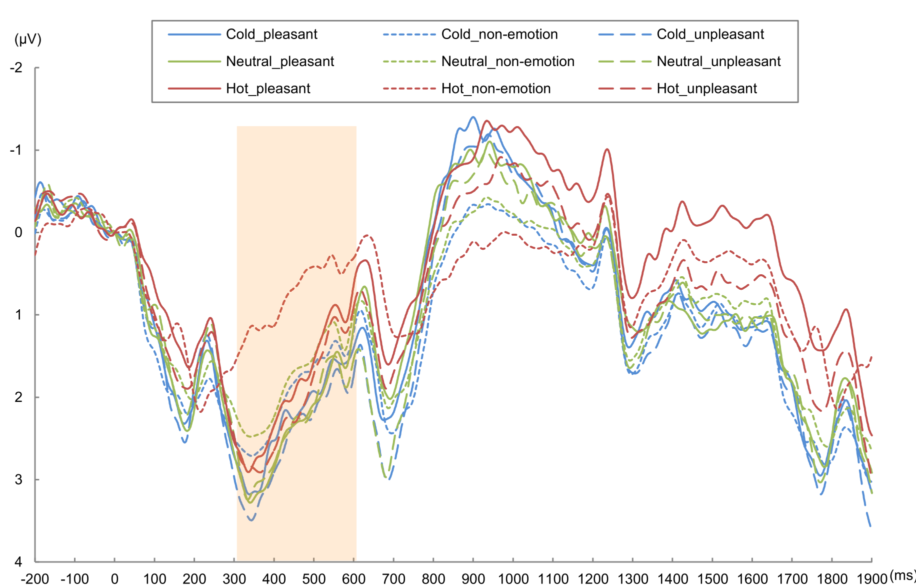

Fig. 5. Grand-averaged ERPs on parietal sites.

Table 4
Result of two-way indoor temperature × emotion repeated-measure ANOVA on parietal sites.

	F	*df*	P
Indoor temperature × emotion	1.39	4, 546	0.237
Indoor temperature	4.09*	2, 273	0.018
Emotion	25.35***	2, 272	0.000

*: p < 0.05, **: p < 0.01, ***: p < 0.001.

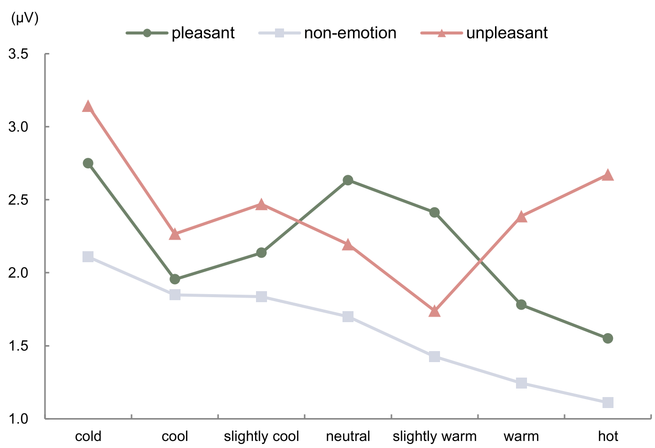

Fig. 6. Emotion in parietal sites depending on subjective thermal sensation vote.

Table 5
Result of two-way mean thermal sensation vote (TSV) × emotion repeated-measure ANOVA on parietal sites.

	F	*df*	p
Mean TSV × emotion	02.08*	12, 538	0.017
Mean TSV	01.17	6, 269	0.325
Emotion	27.68***	2, 268	0.000

*: p < 0.05, **: p < 0.01, ***: p < 0.001.

sites depending on participants' subjective thermal sensations. LPPs from non-emotional picture showed the lowest LPP values. Meanwhile, LPPs from pleasant pictures were higher than those from unpleasant pictures when participants answered that they felt neutral or slightly warm; however, they were lower in all other cases.

Table 5 shows the results of the two-way mean subjective thermal sensation (mean TSV) × emotion repeated-measure ANOVA, which examined the differences in the LPPs elicited across the parietal site event-related potentials (ERPs) upon the presentation of pleasant, unpleasant, or non-emotional pictures in various indoor temperature environments. There was a significant interaction between mean TSV and emotion ($F(12, 538) = 2.08$, $p < 0.05$), suggesting that the effect of mean subjective thermal sensation differed depending on emotion type although the interaction between indoor temperature and emotion was not significant, as illustrated above. Participants who had a neutral or slightly warm sensation had higher LPP when they saw pleasant pictures than unpleasant pictures; however, all other cases showed higher LPP with unpleasant pictures. Emotion also had a significant main effect ($F(2, 268) = 27.68$, $p < 0.001$), indicating that emotional processing differed with valence regardless of subjective thermal sensations. However, the main effect of mean TSV was not statistically significant ($F(6, 269) = 1.17$, $p > 0.05$).

4. Discussion

Based on the psychological theories of emotion, the present study treated emotion as resulting from somatic responses; neural changes. We analyzed event-related potentials (ERPs) from 139 participants to reveal the effect of indoor temperature on emotions.

Late positive potential (LPP) is generally observed in centro-parietal sites at relatively later time windows when emotional arousal is elicited [20,21,25,26]. In the present study, LPP was greater for emotional (pleasant and unpleasant) stimuli than non-emotional stimuli in parietal sites P3 and P4 under all experimental conditions (cold, neutral, and hot indoor temperature). Thus, based on the results of the prior studies mentioned above, the current results suggest that all participants felt positive or negative emotions depending on the type of pictures they saw.

The results can be summarized as follows.

Since participants felt same indoor thermal condition differently, the physical indoor temperature itself had no direct significant influence to induce pleasant or unpleasant emotions. However, the aspect of pleasant or unpleasant emotional processing was significantly different depending on participants' subjective thermal sensation.

Moreover, pleasant emotions were expressed more when participants' thermal sensation was neutral and slightly warm, whereas unpleasant emotions were expressed more in all other cases.

LPP is elicited when there is perceptual encoding, and the amplitude of LPP increases when people are more aroused [20,22,36]. Most previous studies on emotion are about the valence or arousal effect of emotional stimuli, physical characteristics of the stimuli, or emotional context, which explored emotional processing by separate stimuli [16,19,26,37,38]. However, the present study found that different emotional processes can be elicited from the same stimuli by changing the ambient temperature.

The International Affective Picture System (IAPS) used in this study consists of various pictures with different valence and arousal, and in most cases, unpleasant pictures have higher arousal value than pleasant pictures [22]. The LPP elicited when there was an emotional processing was provided as a basis of the arousal effect [17,19,38], and the negativity effect was primarily explored as the LPP responded robustly to unpleasant emotion with higher arousal [21,24,39,40]. However, as the negativity bias is only one example of intrinsic motivational relevance from emotional stimuli [19,21,22,25], motivationally relevant stimuli include not only unpleasant emotional stimuli such as life-threatening pictures but also appetitive stimuli like sexual pictures [20,41]. In this context, one study indicates that there would be a positivity bias if the arousal level is controlled [36]. Although many researches have provided evidence of the negativity bias [21,24,26,40], some researches have reported that responses of pleasant stimuli were more sensitive [16,18,41–44]. Even though no research mentioned positivity bias directly, these researches explained that there was a higher-order level of emotional processing for why people respond more sensitively to pleasant stimuli than unpleasant stimuli, which is called deep processing.

A different aspect of emotional processing was observed in this study depending on the subjective thermal sensation. There was a positivity bias, indicating that people react more to pleasant stimuli than to unpleasant stimuli when the thermal sensation vote was neutral and slightly warm; on the other hand, a negativity bias was observed that indicates that people respond more robustly to unpleasant stimuli than pleasant stimuli in all other cases. In other words, it suggests that there is a deep processing of emotional stimuli when people feel neutral or slightly warm, whereas immediate emotional processing happens when they feel hot (TSV; warm or hot) or cold (TSV; cold, cool, or slightly cool). Therefore, it would be good for deep processing to make people feel neutral or slightly warm and good for immediate processing to make people feel hot or cold. In one research that explored attention depending on the indoor temperature through electroencephalogram measurements [45], relatively lower temperature (PMV −1) is better for selective attention whereas higher temperature is better for continuous attention (PMV 0, PMV +1). The result of this study agrees with previous research in that a different thermal environment is needed for different attention levels.

In the adaptive comfort model, thermal comfort is described as being influenced by physiological, behavioral and psychological adaptive processes [1]. As psychological variables expectation and habitual adaptation are mentioned in section 1. However, the psychological aspects are not sufficiently described yet. Psychological adaptation affect to thermal sensation, however thermal sensation affect to psychology as well, like emotion on this research. This changed emotion would be affect to thermal sensation again and this may be formed a loop.

Many adaptive comfort studies reported that the thermal environment and thermal sensation affect productivity [46–53]. There is a study that observed the effects of elevated temperature on human performance [52]. The results showed that discomfort caused by hot thermal sensation had a negative effect on performance. Another study concluded that adaptive comfort model can save energy considerably without affecting productivity [54]. Furthermore, it is said that no significant difference in students' learning performance between AC and NV rooms seemed to be due to satisfaction and adaptation opportunities [55]. Meanwhile, a study in the field of economics noted that people's productivity was higher when they felt positive emotions [56]. Combining the results of the previous studies mentioned above and the present study suggests that the indoor thermal environment primarily affects the thermal sensation and then has a secondary effect on productivity or emotion based on the thermal sensation. Furthermore, because these secondary factors can affect each other, this study suggests that it is important to provide an indoor environment that is suitable for the purpose of the space.

Studies that explored occupants' thermal sensation or psychological response to indoor temperature have been conducted in the psychological and built environmental fields separately [9–11,45,57]. Studies conducted in the psychological field lack consideration of the physical thermal environment, whereas those in the built environment field have focused limitedly on stress or attention owing to the shortage of previous studies. The present study is different from other previous studies in this regard; moreover, it is observed that it is possible to elicit different emotional processes from the same stimuli by changing the ambient temperature by merging indoor environmental quality field and psychology. Further physioanatomical studies based on brain science are required for a more obvious interpretation of the mechanisms that influence the result of this study.

5. Conclusion

The present study conducted a chamber experiment and measured brain waves to explore the effect of the indoor thermal environment on occupants' emotion.

Based on the physiological theories of emotion, we measured emotional responses via brain wave patterns derived from 139 physically and mentally healthy participants. The event-related potentials (ERPs) emerging in response to an emotion-eliciting stimulus were recorded at three different indoor temperatures (PMV −2, PMV 0, and PMV +2). The late positive potential (LPP) that developed in a positive direction between 300 and 600 ms after stimulus onset was selected for analysis.

As a result, although the physical thermal environmental factor did not affect emotions directly, significantly different emotional processing is identified depending on the subjective thermal sensation. It is because participants felt different thermal sensations even though they were in the same physical environmental condition, and it suggests that there is a difference in the emotion elicited depending on the individual thermal sensation. A stronger positive emotion was observed when participants felt neutral or slightly warm, whereas negativity bias was presented in other cases—cold, cool, slightly cool, warm, or hot.

The above-mentioned results indicate that the indoor thermal environment significantly affects occupants' emotion as well as health and productivity.

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