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The occupants' stress on each PMV condition – chamber study using brain wave

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Abstract

This study is designed to investigate the relationship between the thermal comfort environment and stress using brain wave analysis. To achieve this purpose, an experimental approach in a climate chamber based on PMVs was adopted. Environmental factors were set with the PMV scale ranging from -3 to +2. The brain waves of each of the participants (N=7; males) were measured in six conditions, in the PMV order from cold to hot, i.e. one condition per day. The results suggest that the participants felt least stressed under the PMV 0 and most stressed under the PMV -3 and +2. In addition, the stress levels arising from the brain waves varied with time. For an immediate exposure, an order effect was found. Participants felt more stressed in the process of PMV change from 0 to +1, compared to PMV +1 to PMV +2. However, in one hour, they felt most stressed in the hottest environment condition.

Keywords: Thermal comfort, Stress, Brain wave (EEG)

1 Introduction

Numerous studies on thermal comfort have discussed human thermal sensation with regard to physical environment in a climate chamber based on verbal voting. The results of these studies have led to the development of thermal comfort indices such as PMV (Fanger, 1970), and these indices have contributed to a more pleasant indoor thermal environment plan.

Some studies examined physiological reactions of humans to the surrounding physical environment. Representative studies discussed the interaction between physical environment and human body by measuring skin temperature or blood flow and by predicting thermal comfort state of occupants (Arens et al., 2006; Gagge et al., 1967; Kingma et al., 2011; Savage & Brengelmann, 1996).

More recently, brain has recently become the link between human physiology, on the one hand, and cognitive science, on the other hand. The remarkable development of brain sciences provided various clues for understanding human body and mind, and the new methodologies of brain sciences have integrated into different research fields. The research area that focuses on thermal comfort and investigates thermal environment around human body and relevant human reactions should join the trend. Accordingly, this study intended to use brainwave measurement in the field of thermal comfort.

In the first step of this experiment, the degree of stress in occupants according to 6 PMV conditions was examined by brainwave measurement. This degree of stress is the level of relaxation of unstressed occupants. The results of this study can be used for in future for planning the relaxed indoor environment.

2 Methods

2.1 Experimental Condition

The experiment was carried out in the 3.7m×4.0m×2.0m (W×D×H) climate chamber in March, 2013. Air temperature was set with the PMV scale from -3 to +2 (see Table 1). The control conditions for other environmental factors are shown in Table 2. All participants were exposed to six different thermal conditions. The pre-chamber was set to the neutral temperature with the PMV scale equal to zero. Participants waited in the pre-chamber to adapt to the thermal neutral environment before the experiment.

Table 1. Climate chamber conditions based on PMVs.

PMV scale	Air temperature (°C)	
	Setting value	Actual value
-3	15.80	15.88±0.14
-2	18.80	18.86±0.11
-1	21.80	21.81±0.06
0	25.00	25.01±0.06
+1	28.00	28.01±0.05
+2	31.00	30.99±0.13

Table 2. Control conditions for other environmental factors

Factors	Conditions controlled
Relative Humidity	50 %
Air velocity	< 0.1 m/s
Participants' clothing values	0.7 clo
Participants' metabolic rate	1.0 met
Intensity of illumination on the desk surface	893.41 lx

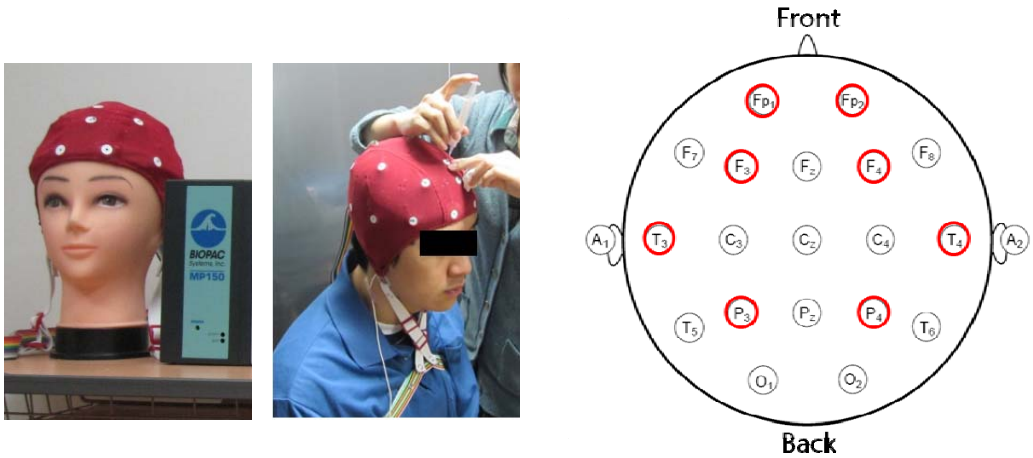
2.2 Experimental tools and procedures

EEG (Brain waves) is the recording of minute electrical activity on the surface of the scalp. The waves are divided into bands by frequency in the high-to-low order: Delta, Alpha, Beta, and Gamma. Each band has varying characteristics and reflects the function of the brain and the activity of the nervous system. Alpha waves are mainly used to measure a relaxed state of human body. On the contrary, beta waves are used to measure a tensed state. While aroused state includes positive effects, a negative highly tensed state is measured by high beta waves. Gamma waves appear when human body undergoes extreme agitation.

Table 3. EEG frequency bands.

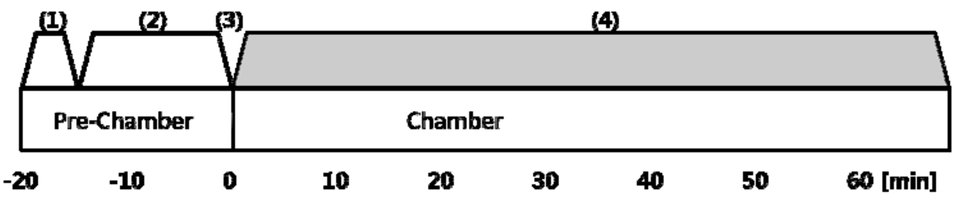
Frequency	EEG rhythm	Neural functions and behaviors
~ 4Hz	Delta (δ)	Sleep (non-REM)
4 ~ 8 Hz	Theta (θ)	Sleep, Sleepiness
8 ~ 13 Hz	Alpha (α)	Physical relaxation, Mental inactivity
13 ~ 30 Hz	Beta (β)	Mental activity, Arousal, Strained
30Hz ~	Gamma (γ)	Nervousness, High-level information processing

In this experiment, 8 EEG channels of MP 150 (Biopac System Inc., Santa Barbara, CA, USA) were applied to record EEG and to analyze the process of stress. Cap-style brain wave electrodes were placed onto the frontal lobe, the temporal lobe, and the parietal lobe (Fp1, Fp2, F3, F4, T3, T4, P3, and P4) in accordance with the international 10-20 system of electrode placement (Jasper, 1958), and a reference electrode was an earlobe (A1) (Figure 1). Seven healthy male undergraduates participated in the experiment. Their participation was approved by the IRB board at Yonsei University. Figure 2 shows the experimental procedure, which was identically implemented for all the participants. All of them were exposed to the conditions in the order of PMV from cold to hot (PMV-3 → PMV-2 → PMV-1 → PMV0 → PMV+1 → PMV+2). They participated in one condition per day in the same time period. To control the biorhythm of the day, the experiments were divided into three time periods: morning, afternoon, and evening. Each participant wore the experimental suit (0.7clo) and adapted to the neutral (PMV=0) condition in the pre-chamber. After the brain electrodes were attached to each participant in the pre-chamber, the participant was allowed to enter the climate chamber. Then, the participant was instructed to read materials for 65 minutes. EEG data associated with stress were collected two times (between 2~4 minutes and between 63~65 minutes). In this experiment, the relative Alpha (α) wave related with relaxation reflecting the non-stressed status, and the relative High-beta (hβ) wave related to arousal as a stressed status were measured. All EEG data were analyzed after removing artifacts caused by EOG (electrooculogram) and filtering.



a) b)

Figure 1. Electrodes; a) cap-style electrodes, b) electrodes placements



(1) Pre-chamber | Put on experimental suit (0.7clo)
(2) Pre-chamber | Adjust to neutral temperature & Attach brainwave electrodes
(3) Pre-chamber | Enter the climate chamber
(4) Chamber | Read materials & Collect EEG data

Figure 2. Experimental procedure

3 Results

3.1 Stress-related brain mapping on PMVs

Brain mapping analysis for the visualization of the EEG power was conducted using the 'BrainMap-3D' S/W (Laxtha, Daejeon, Korea). EEG data that contained artifacts were excluded from the final dataset. The mean of relative power for each region and frequency were used to analyze the brain mapping. The relative Alpha wave associated with physical relaxation and mental inactivity was analyzed to show the inverse situation of stress, and the relative High-beta wave associated with high arousal was analyzed to show the degree of stress. Values of relative power were expressed by colour in the high-to-low order: red, orange, yellow, green, blue, and violet. Visualizations of the mapping for the relative Alpha wave and the relative High-beta wave between 2~4 minutes are as follows (see Figure 3).

In case of PMV -3 (15.8°C/50%), an activity of the relative Alpha wave measured well at the back of the head was shown only in the parietal lobe (P3, P4). In case of PMV -2 (18.8°C/50%), an activity of the relative Alpha wave expanded from the parietal lobe (P3, P4) to the frontal lobe (F3, F4). It means that the participants felt more relaxed in PMV -2 than in PMV -3. In case of PMV -1 (21.8°C/50%), an activity of the relative Alpha wave expanded to the temporal lobe (T3, T4). Reactions of the prefrontal lobe (Fp1, Fp2) were not powerful; however, the overall relaxation increased. In case of PMV 0 (25.0°C/50%), an activity of the relative Alpha wave was observed in almost every part of the brain. The reaction of the right temporal lobe (T4) decreased; however, it can be assumed that a thermal indoor environment with PMV scale reaching 0 was most relaxing for the participants. In case of PMV +1 (28.0°C/50%), an activity of the relative Alpha wave decreased. The participants were starting to find it difficult to relax. In case of PMV +2 (31.0°C/50%), an activity of the relative Alpha wave expanded to the frontal lobe (F3, F4). This suggests that the participants were perhaps not relaxed but rather drowsy from the heat. Alpha wave can be activated as a state opposite to the tension state caused by loosening of the body by heat.

In case of PMV -3 (15.8°C/50%), a stronger activity of the relative High-beta wave was observed on both sides of the temporal lobe (T3, T4). This means that the participants were under a lot of stress. In case of PMV -2 (18.8°C/50%), the overall activity of the relative High-beta wave decreased. This can be explained by the participants' adapting to the cold environment after being exposed to PMV -3. In case of PMV -1 (21.8°C/50%), an activity of the relative High-beta wave was observed on both sides of the temporal lobe (T3, T4); however, the value of the left temporal lobe (T3) was lower than in the PMV -3 condition. In case of PMV 0 (25.0°C/50%), the greater part of the brain appeared bluish except for the right temporal lobe (T4), and the reaction of the left temporal lobe (T3) decreased more. It can be assumed that a thermal indoor environment with PMV scale reaching 0 was the best for the participants' stress-free state, as they showed the lowest stress level in this thermal indoor environment. In case of PMV +1 (28.0°C/50%), the values of the relative High-beta wave were most activated, and, as with PMV -3, the stronger activity of the relative High-beta wave was observed on both sides of the temporal lobe (T3, T4). This means that the participants were under a lot of stress in this thermal environment. In case of PMV +2 (31.0°C/50%), the activity of the relative High-beta wave decreased in the overall part of the brain similar to the PMV -2 condition. It can be assumed that participants might have adapted to the hot environment after being exposed to PMV +1. All participants were exposed to the conditions ranging from discomfort (PMV -3) to comfort (PMV 0) and then from comfort (PMV 0) to discomfort (PMV +2). Throughout this process, the results suggest that the participants felt much stress when the condition changed from comfort (PMV 0) to discomfort (PMV +1). Thus, they showed a more stressed status under PMV +1 than PMV +2.

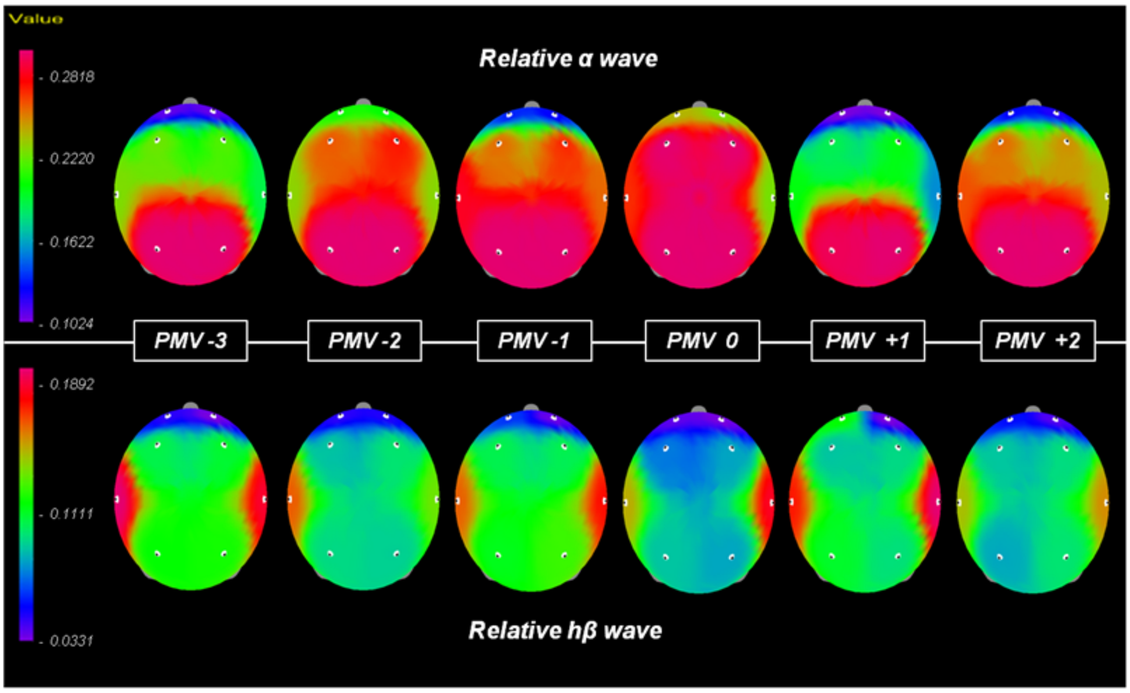


Figure 3. Mapping for relative Alpha wave and the High-beta wave based on PMVs (between 2~4 minutes)

3.2 The change of EEG with time

As concerns the mapping of the relative Alpha wave and the High-beta wave based on PMVs (see Figure 3), the relative alpha waves typical for a stress-free relax state became more activated in the direction from the parietal lobe (P3, P4) to the frontal lobe (F3, F4) as the experimental settings changed from PMV -3 (the coldest environment) toward the PMV 0 (neutral thermal environment). On the other hand, those relative High-beta waves characterizing the stressed state were most activated in the temporal lobe under all PMV conditions. In this study, the relative alpha waves (relax state) became more activated along the parietal lobe (stable state) and the frontal lobe (recognition, emotion) as they approached the thermal neutral environment. In addition, the relative High-beta waves (stressed state) became more activated along the temporal lobe (stress-related emotion). Based on these findings, the PMV-based activation analysis of the relative alpha waves along the frontal lobe (F3, F4) and the relative High-beta waves along the temporal lobe (T3, T4) can be summarized as follows (see Figure 4).

Figure 4 shows the relative Alpha wave in the frontal lobe between 2~4 minutes. The power of the relative Alpha wave showed the highest value in a thermal indoor environment with PMV 0; on the contrary, it showed the lowest value in a thermal indoor environment with PMV +1. Consequently, in case of the relaxation associated to the relative Alpha wave, a thermal indoor environment characterised by PMV 0 was most relaxing. By contrast, the participants found it difficult to relax in a thermal indoor environment with PMV -3 and +1. In case of a hot thermal indoor environment (PMV +2), participants were possibly drowsy from the heat. Then, the value of the relative Alpha wave increased due to the brain inactivity. It highlights drowsiness, a condition that is somewhat different from relaxation.

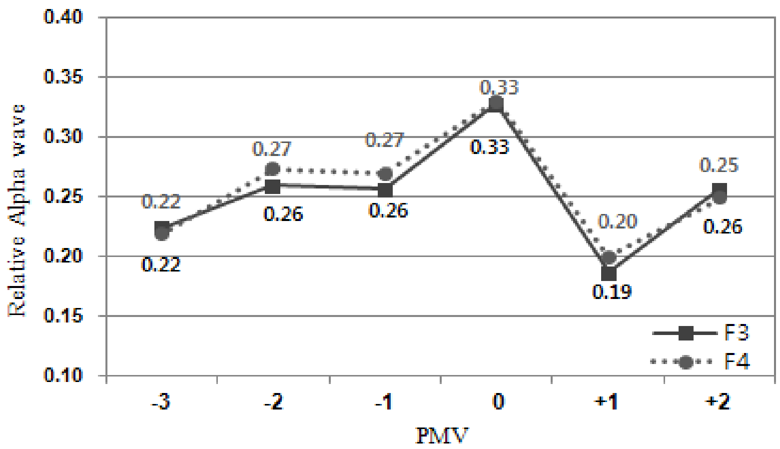


Figure 4. Relative Alpha wave in the frontal lobe based on PMVs (between 2~4 minutes)

Figure 5 shows the relative High-beta wave in the temporal lobe between 2~4 minutes. The power of the relative High-beta wave was slightly different between the left temporal lobe and the right temporal lobe. In case of the left temporal lobe (T3), the power of the relative High-beta wave was the lowest value in a thermal indoor environment with PMV, 0 and the highest in a thermal indoor environment with PMV -3; conversely, in case of the right temporal lobe (T4), it yielded the lowest value in a thermal indoor environment with PMV -2 and the highest value in a thermal indoor environment with PMV +1. Consequently, in case of the stress associated to the relative High-beta wave, a thermal indoor environment with PMV 0 reduced the participants' stress most effectively. By contrast, participants in a thermal indoor environment with PMV -3 and +1 were in most stressed condition

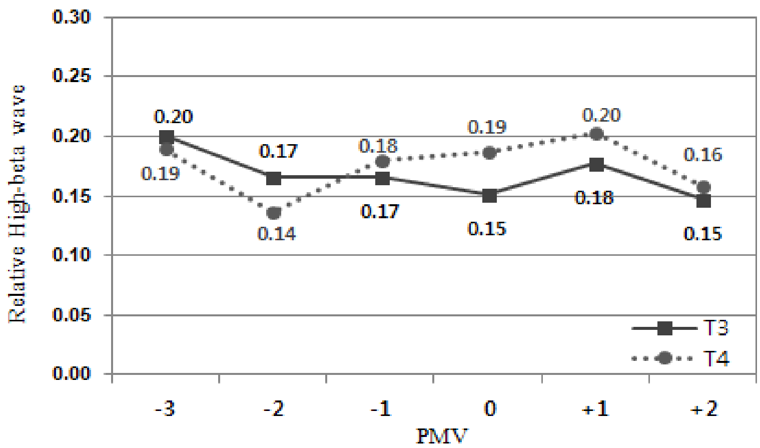


Figure 5. Relative High-beta wave in the temporal lobe based on PMVs (between 2~4 minutes)

Figure 6 shows these stress-related relative High-beta waves measured in the temporal lobe after one hour (63~65 minutes). The reaction of the right temporal lobe (T4) was the highest under PMV -1, while the reaction of the left temporal lobe (T3) was the lowest under PMV -2 and -3. The most remarkable difference of High-beta waves after one hour (63~65 minutes), compared to 2-4 minutes, was that they became more activated under PMV +2 previously under PMV +1. This phenomenon was observed in both the left temporal lobe (T3) and the right temporal lobe (T4).

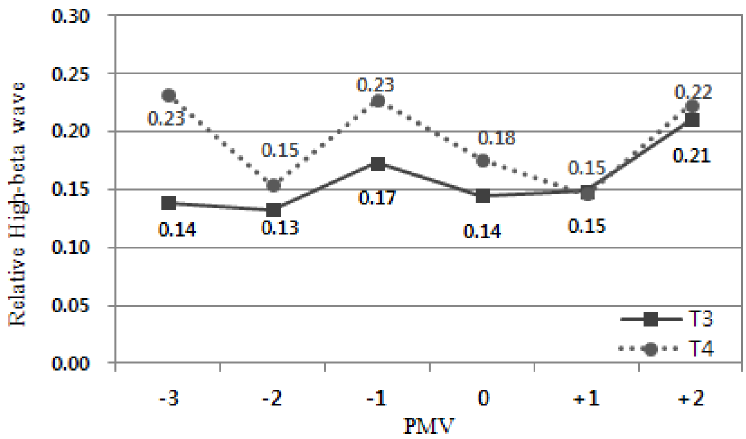


Figure 6. Relative High-beta wave in the temporal lobe based on PMVs (between 63~65 minutes)

4 Conclusions

This study was conducted to examine the EEG associated with stress across six PMV conditions. The following conclusions can be drawn based from the results of this study. First, the participants felt least stress under PMV 0 (thermal neutral environment) and the highest level of stress under PMV -3 (the coldest environment). In an hour, they felt most stress under PMV +2 (the hottest environment) as well. Second, the stress levels based on the EEG varied with time. For an immediate (2~4 minutes) exposure to all indoor thermal environments (from PMV -3 to PMV +2), the participants felt more stressed in the process of change from thermal neutral environment (PMV 0) to the hotter environment (PMV +1) than in the change from PMV +1 to PMV +2. This showed the order effect of the experiment. It can be explained by the participants' feeling much stress when they were exposed to the unexpected discomfort in the sequence where there was an effect of the previous experience in spite of more than one-day interval. On the contrary, in an hour, they felt most stressed in the hottest environment.

Acknowledgements

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