Evaluation of Thermal Comfortable Feeling by EEG Analysis

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Abstract:

Thermal comfort by wearing clothes is the important element which gives influence to a clothing comfort. The thermal comfort of clothes have been evaluated by sensory test and physical property of clothes material. To evaluate a thermophysiological comfort, a new evaluation method which measures the physiological response such as electroencephalogram(EEG) is attracting the attention of many people. In the chilly environment, the EEGs in two kinds of thermal conditions : with and without clothes were measured. By utilizing the chaos analysis, the behavior of the obtained EEGs were quantitatively expressed in the correlation dimension. As a result, the correlation dimension of the EEGs in being thermal comfortable feeling by putting on clothes, was bigger than the correlation dimension of the EEGs in being cold and discomfort. These results suggest that chaotic analysis of EEG is effective to the quantitative evaluation of thermal esthesis.
Keywords:Electroencephalogram, Correlation dimension, Thermophysiological comfort, Comfortable feeling, Wearing clothes

1. Introduction

One of the most important roles of wearing clothes is maintaining thermal balance of the human body and thermophysiological comfort. Thermophysiological comfort is a fundamentally important element of clothes since they are intended to worn in various environments. In order to design some clothes, a condition of wearing clothes needs to be objectively evaluated by using a criterion to describe psychological and physiological comfortable feeling.

Currently, thermal comfort has been evaluated by a sensory test[1] or the physical property of clothes material[2]. However, it is difficult that expresses and understands the comfortable feeling in the psychology terms, because the terms lack the objectivity. Only by measuring the physical property of garment material, it is not possible human accurately.

Recently, a measurement of physiological response is interest as a physical criterion to describe the clothing comfort[3][4]. Methods for evaluating the comfortable feeling from the measurement of the physiological response has the following advantages:(1) The comfortable feeling under the unconscious can be evaluated. (2) The measurement of the comfortable feeling is continuously possible. (3) There is the objectivity in obtained data, because the measured data is the physical quantity got from human body.

In this paper, we would like to propose a method that textiles are evaluated by psychological and physiological responses. In the chilly environment, we will dress to maintain the thermal balance of the human body. We consider that the thermal comfort of clothes can be evaluated by comparing the psychological and physiological responses with clothes and one without clothes, We measured the thermal esthesis, comfortable feeing and arousal level as psychological response and the alpha wave of EEGs as physiological responses. An equal result was not obtained so the EEG was considered a chaos system even if the conditions were similar. Chaotic analysis is useful as a method to analyze an EEG with a very complicated dynamism. The correlation dimension is well known as a criterion to describe chaos(complexity) of time series data and is one method of chaos system analysis. The correlation dimension becomes large value, as the behavior of the EEGs is more complicated.

In this paper, we first constructed the measurement procedure of the EEG for clothing comfort in a chilly environment. Second, we calculated the correlation dimension of the EEG with and without clothes. Finally, comparing the results of the sensory test, we confirm the possibility of the correlation dimension as an evaluation criterion for thermal comfort.

2. Measurement Procedure

The measurement procedure of EEG and subjective thermal comfort with and without clothes is shown in the following. Ten women(college students) took part in the sensory test. These subjects rested , seated with eye closed in the experiment room. The experiment room environment was at 15??, 65 % RH. The subjects without clothes wore only a cotton T-shirt over a brassiere. Subjects with clothes wore a coat (long sleeved cardigan) over a T-shirt. During the experiment, the EEG was recorded for 1 minute and at 3 experiment processes: (1) with clothes (2) without clothes for 30 minutes (3) with clothes, again. The thermal esthesis comfortable feeing and arousal level were also measured by a sensory test. These were expressed by a numerical grade from -100 to 100. The EEG was measured by unipolar derivation. Ten Ag-AgCl electrodes were placed on F_{p1}, F_{p2}, F_3, F_4, T_3, T_4, C_3, C_4, P_3, and P_4 as shown into Figure 1. According to the International 10-20 system reference electrodes were placed on both earlobes. We set as contact impedance of the electrodes became less than 5k? .

The EEGs were amplified by an electroencephalograph (MP100WS (EEG100A), BIOPAC Inc.), A/D-converted with a 200 Hz sample frequency, and recorded into a computer. The actual data used for calculating the correlation dimension were EEGs of 40 seconds with the for first and last 10 seconds of the original data cut. The number of data of 1 signal was 8000 points. A band pass filter with a bandwidth of 8 to 13 Hz was applied to the sectioned EEG to obtain alpha waves. When artifacts were interfused to EEG, such as EMG by blinking, the data was removed.

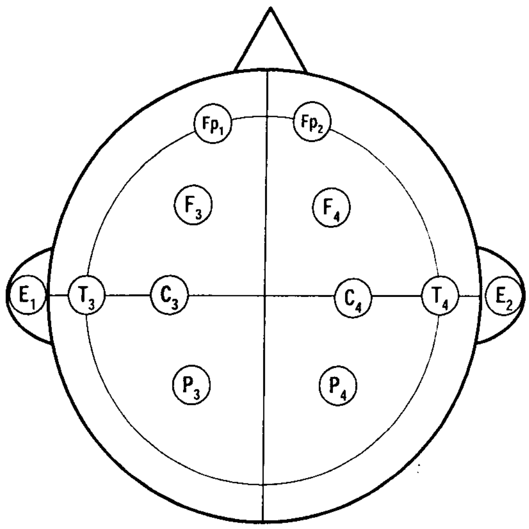


Figure 1: Electrode montage

3. Correlation dimension analysis

The complicated behavior of EEG can be quantitatively described by correlation dimension that is one of the fractal analysis. If EEG is deterministic chaos, correlation dimension calculated from the EEG converges in constant. If EEG is not deterministic chaos, correlation dimension calculated from the EEG diverges.

In this study, according to Grassberger and Procaccia method[5], correlation dimensions for each EEG are calculated by calculating correlation integral for the attractor reconstructed by using Takens's embedding theory[6]. An abstract of a calculus is shown to the following.

Recall that we are considering EEG as a dynamical system. EEG is obtained as one-dimensional times series $\{x(1), x(2), ..., x(t)\}$. The one dimensional time series data is reconstructed as a trajectory that is equivalent with a trajectory in the dynamical system with m-dimensional space. Concretely, we get m-dimensional vector

$$\begin{aligned} \mathbf{x}(1) &= [x(1), x(1+\tau), ..., x(1+(m-1)\tau)] \\ \mathbf{x}(2) &= [x(2), x(2+\tau), ..., x(2+(m-1)\tau)] \\ &\vdots \\ \mathbf{x}(t) &= [x(t), x(t+\tau), ..., x(t+(m-1)\tau)], \end{aligned} \quad (1)$$

where τ and m are the time-delays and the embedding dimension, respectively, where, we let the time-delay τ equal to $80ms$, because autocorrelation function of EEG were the smallest.

If one point of reconstructed trajectory is $\mathbf{x}_i \in R^m$, the correlation integral $C_m(r)$ is defined as

$$C_m(r) = \lim_{N \to \infty} \frac{2}{N(N-1)} \sum_{i<j} H(r - |x(i) - x(j)|) \quad (2)$$

where, N is the number of data. Here $H(X)$ is the Heviside function. The correlation dimension $D(m)$ is defined as

$$D(m) = \lim_{r \to 0} \lim_{N \to \infty} \frac{\log C_m(r)}{\log r} \quad (3)$$

Actually, increasing m, $D(m)$ is calculated, and we get convergence value of $D(m)$ as the correlation dimension.

4. Results

4.1. Sensory test

Table1 shows the results of the sensory test for 10 subjects. If the score is high, subjects feel comfortable, warm and arousal state. In with clothes, subjects didn't feel very cold or uncomfortable. In without clothes, subjects felt very cold and uncomfortable. Almost every subject feels warm and comfortable in with clothes. On other hand, the subjects feel cold and uncomfortable Also, almost subject is high arousal level in with clothes and low arousal level in without clothes.

4.2. Spectrum and trajectory of EEG

Figure 2 shows the time-series plot of EEG measured from P_3 for subject A . Fourier spectrum is shown into Figure 3. Phase-space plots are shown into Figure 4. The EEG with clothes has a broad spectrum and the phase-space trajectory suggestive of a wide point attractor. The EEG without clothes is quite periodic as shown by the spike and the trajectory suggestive of a convergent attractor.

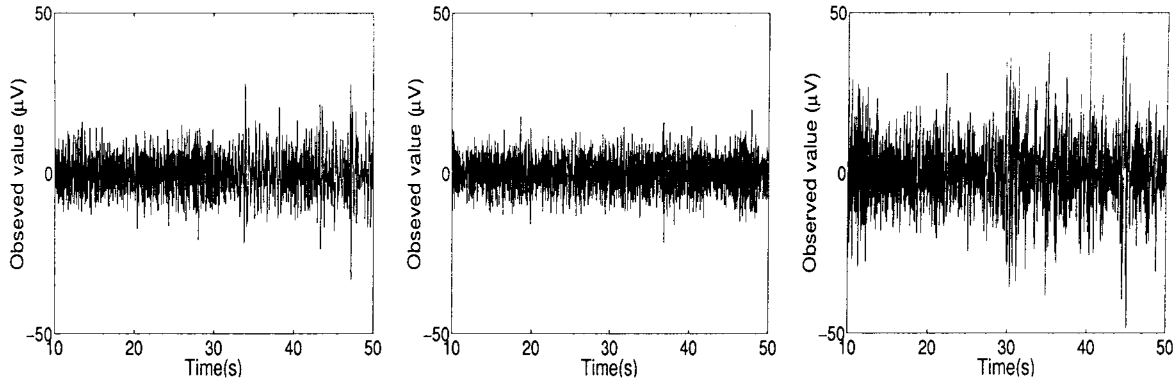
In the condition of wearing clothes, the broad spectrum and wide trajectory are obtained from EEG of all subjects. In the condition of without clothes that subjects are discomfort and cold, the spectrum has the spike, and the trajectory became like a weak chaos for each subjects.

4.3. Correlation dimension

Table 2 shows mean of correlation dimensions for 10 subjects in the 3 processes at 10 electrode placements. In the almost every placement, we could inspect that the correlation dimension of with clothing is higher than one of without clothing.

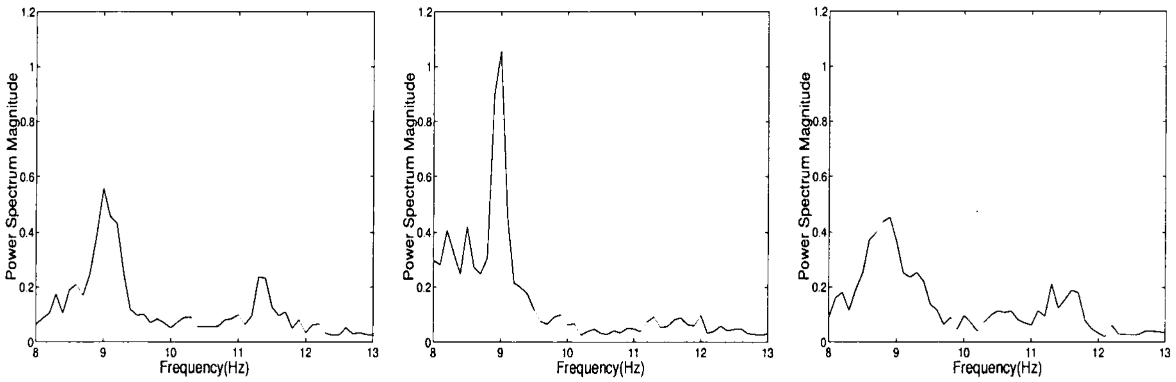
Table 1: Comfort, thermal esthesis and arousal level

Sub.	Items	With clothes	Without clothes	With clothes (again)
A	Thermal esthesis	-40	-90	-20
	Comfort	-10	-90	-20
	Arousal	30	-50	20
B	thermal esthesis	-20	-40	0
	Comfort	-10	-30	10
	Arousal	50	10	20
C	Thermal esthesis	-10	-20	-10
	Comfort	-40	-20	-10
	Arousal	0	-10	-10
D	Thermal esthesis	-30	-60	-40
	Comfort	-10	-30	-20
	Arousal	50	-30	-10
E	Thermal esthesis	0	-40	-10
	Comfort	-10	-30	-10
	Arousal	0	30	10
F	Thermal esthesis	-10	-50	-10
	Comfort	10	-40	-10
	Arousal	40	20	20
G	Thermal esthesis	0	-50	-20
	Comfort	0	-30	-50
	Arousal	20	30	20
H	Thermal esthesis	-20	-95	-50
	Comfort	80	-10	0
	Arousal	70	0	0
I	Thermal esthesis	-30	-100	-60
	Comfort	-20	-100	-30
	Arousal	10	-60	-10
J	Thermal esthesis	0	-60	-50
	Comfort	0	-60	-40
	Arousal	10	-10	-10



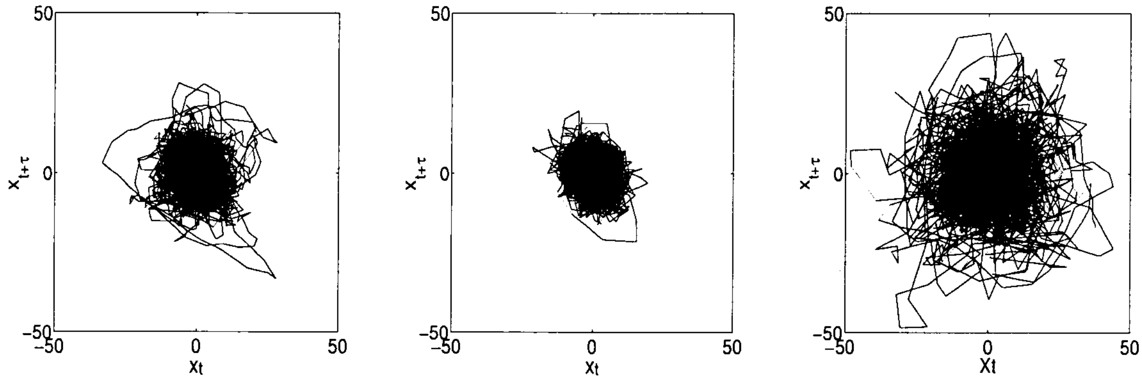
(a) With clothes (b) Without clothes (c) With cloth, again

Figure 2: Alpha wave of EEG



(a) With clothes (b) Without clothes (c) With cloth, again

Figure 3: Spectrum of EEG



(a) With clothes (b) Without clothes (c) With cloth, again

Figure 4: phase-space trajectory

Table 2: Mean and standard deviation of Correlation dimension in the 3 processes at 10 placements

E.P.	With clothes		Without Clothes		With Clothes (again)	
	Ave.	STD	Ave.	STD	Ave.	STD
F_{p1}	5.69	0.23	5.38	0.17	5.50	0.15
F_{p2}	5.30	0.39	4.89	0.35	5.60	0.31
F_3	5.73	0.77	4.91	1.13	5.19	1.06
F_4	5.61	0.90	5.05	0.87	5.36	0.92
T_3	4.91	0.84	4.34	0.90	5.04	0.91
T_4	6.02	0.81	4.92	1.00	5.44	0.75
C_3	5.47	0.82	4.62	0.81	5.60	0.75
C_4	5.15	0.95	5.13	1.36	5.12	1.00
P_3	5.20	0.94	4.28	1.14	4.76	1.18
P_4	5.50	0.49	4.86	0.54	5.16	1.30

The two-way ANOVA of 3 processes $\times$ 10 placements indicated that significant differences among processes. There were no significant differences between placements and no significant interaction between processes and placements. So we applied multiplex comparison by Tukey method for the measurement condition. As a result, the correlation dimension in the case of without clothes is smaller significantly than it in the case of wearing clothes. Accordingly dynamic behavior of EEG in without clothes that a subject felt cold was more periodic than EEG in wearing. These results show that EEG under the comfortable condition with coat fluctuated to some extent, and it shows deterministic chaos, on the other hand, EEG of fluctuation under the stress condition without coat is small, and it shows weak chaos.

5. Conclusions

In the two kinds of the thermal condition : with clothes in the chilly environment and without clothes in the chilly environment, we measured EEGs, the thermal esthesis, comfortable feeling, and arousal level. The correlation dimension of EEG without clothes was significantly smaller than with clothes. The EEG under the comfortable condition with a coat fluctuated to some extent, and it shows deterministic chaos. On the other hand, the fluctuation of the EEG under stress, without a coat is small, and it showed a weak chaos. It was suggested that the correlation dimension was useful as an index for evaluating thermophysiological comfort because the correlation dimension of the dynamic behavior of the EEG varied by degree of stress.

We conclude that the thermal comfortable feeling can be evaluated by analyzing the brain wave. The correlation dimension of the EEG was different, when the thermal comfortable feeling was different. For almost all subjects, this result was observed in all measurement positions. This is shown that the brain activity differs in the degree of the comfortable feeling. That the behavior of the brain wave becomes monotonous seems to be the result which the homeostasis reflects.

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