Journal of Environmental Science and Engineering A 12 (2023) 117-126
doi:10.17265/2162-5298/2023.04.001

A Study on the Utility of an Electroencephalogram-Based Stress Analysis Method for Seaside and Road Space

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Abstract: Modern society is called the stress society, there has been a growing interest in comfortable living space. Therefore, a lot of studies using biological information have been done to quantitatively assess the effects on the human body in recent years. This study verified quantitatively difference between healing effect and stress reduction effect of sea space and general street space using an inexpensive EEG (Electroencephalogram) machine. The purpose of this study is to verify quantitatively healing effect and stress reduction effect of sea space using the EEG measurement from the psychological analysis by questionnaire survey and the SD (Semantic Differential) method. As a result, EEG and questionnaire results, psychological analysis results can be seen to match, and the effectiveness of the EEG measurement was confirmed.

Key words: Biological information, EEG, questionnaire survey, relaxation degree.

1. Introduction

Since the 1950s, when Japan entered its period of rapid economic growth, social infrastructure, such as roads, railways, ports, and airports, has rapidly developed through civil engineering. Social infrastructure development has played an essential role in defining the structure of the modern state and promoting economic growth in Japan. However, such rapid development has had several adverse consequences, such as traffic congestion, urban and rural disparity, and environmental problems. With Japanese society being increasingly defined by a declining birthrate and aging population, people are becoming more concerned about the quality of urban spaces, including the landscape, focusing more on the realization of a rich living environment that values quality over quantity. The MLIT (Ministry of Land, Infrastructure, Transport and Tourism) has also focused on this theme, and recommended the creation of comfortable living spaces in its 2013 White Paper [1]. Reflecting this trend, Akashi City, Hyogo Prefecture, where this survey was conducted, has set urban development as its basic urban concept in 2030, and is promoting the comfort and peace of mind of people who make use of the blessings of the city, such as nature, history, and culture. We formulate a plan that values feelings [2].

One reason for these aims may be that, in the contemporary world, many people have a high level of stress in their daily and social lives, in what is often termed a "stressful society". In this context, various studies focusing on urban space issues have been conducted, involving the creation of relaxing and healing spaces and comfort evaluations. Such studies suggest that green spaces [3], riverside spaces [4], and seaside spaces have healing and relaxing effects [5].

Questionnaire surveys employing the SD (Semantic Differential) method have often been used for spatial evaluation. In this method, commonly employed in psychological experiments, subjects evaluate spatial targets using quantitative evaluation scales based on

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antonym pairs. Typically, the scales are quantified to enable factor analysis that characterizes the evaluation dimension. And devices for measuring biological information, which had previously been mainly used in the medical field, have become more affordable, and are now utilized in various research fields, including urban space evaluation. For example, biological information, such as saliva amylase [6], pulse waves [7], and walking EEG (Electroencephalogram) results [8], has been used to quantitatively assess the influence of people's spatial perception on their feelings. In another example of EEG-based research in outdoor spaces [9], the effects of riverside, park, and roadside spaces were investigated; however, that study required the use of as many as 16 electrodes.

In the present study, we utilized an affordable and easy-to-wear electroencephalograph, and quantitatively investigated the differences between people's impressions in seaside spaces, which are considered to be conducive to healing and stress-reduction, and common road spaces. In addition, to assess the healing and stress-reducing effects in the seaside spaces, we conducted a questionnaire survey and psychological analysis using the SD method, simultaneously with the EEG measurement, to quantitatively verify the utility of the EEG measurement. As for overseas research results, although there are studies using simple electroencephalographs, there are cases where EEGs were observed while subjects were walking [10]. Since EEG measurement while walking reflects large noise, in this study, the subject is measured while sitting.

2. Method

2.1 Overview of the EEG

A human brain comprises about 14 billion nerve cells, which constantly generate a low level of electricity. In the glossary of the IFCN (International Federation of Clinical Neurophysiology), an EEG is defined as "a record of electrical activity in the brain captured by electrodes placed on the surface of the head, unless otherwise specified" [11]. EEGs can be roughly divided into four types, according to the width of the waveform (i.e., the frequency), as shown in Fig. 1 [12].

When a person relaxes (or is healing), the number of α waves increases and the number of β waves decreases in the brain. On the contrary, when a person feels stress, the α wave decreases and the β wave increases. Thus, by analysing an EEG, we can determine whether a person is taxing their mind (in a stressed state) or not (in a relaxed state), though the precise functions of human emotions and thoughts are still not well known. However, in recent years, overseas research has shown the need for further research on the challenges and opportunities of transfer learning, as EEG measurements are random and non-stationary and difficult to observe [13].

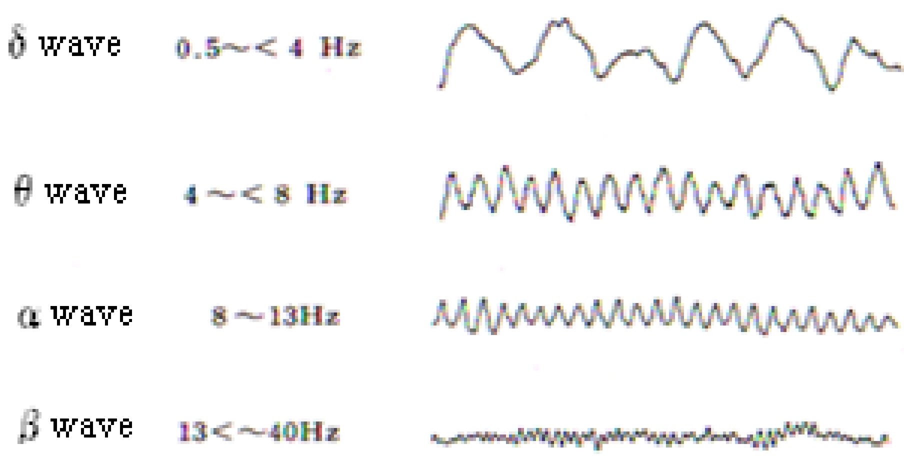


Fig. 1 EEG patterns based on frequency differences.

2.2 Selection of the Electroencephalograph

In this study, we used the Muse Brain System manufactured by Digital Medic Co., Ltd. (Fig. 2). Fig. 3 shows the electrode layout [14]. The specific Muse Brain System used in the study had four electrodes, at O_1, O_2, A_1 and A_2, with the latter two being clip electrodes that were affixed to the earlobes. The so-called reference derivation method was used to generate the EEG (Fig. 3). Fig. 4 shows the attachment of the four electrodes to a subject's head. The EEG records were transferred to a PC (Personal Computer), and the results were displayed on the screen and saved (Fig. 5).

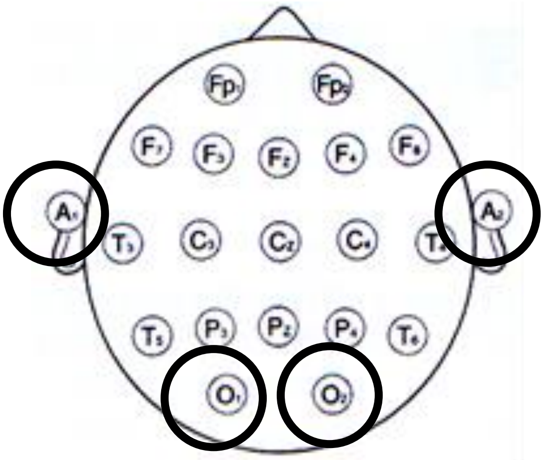


Fig. 3 Electrode positions for the Muse Brain System (had four electrodes).

Fig. 2 Muse Brain System.

Fig. 4 Attachment of the Muse Brain System.

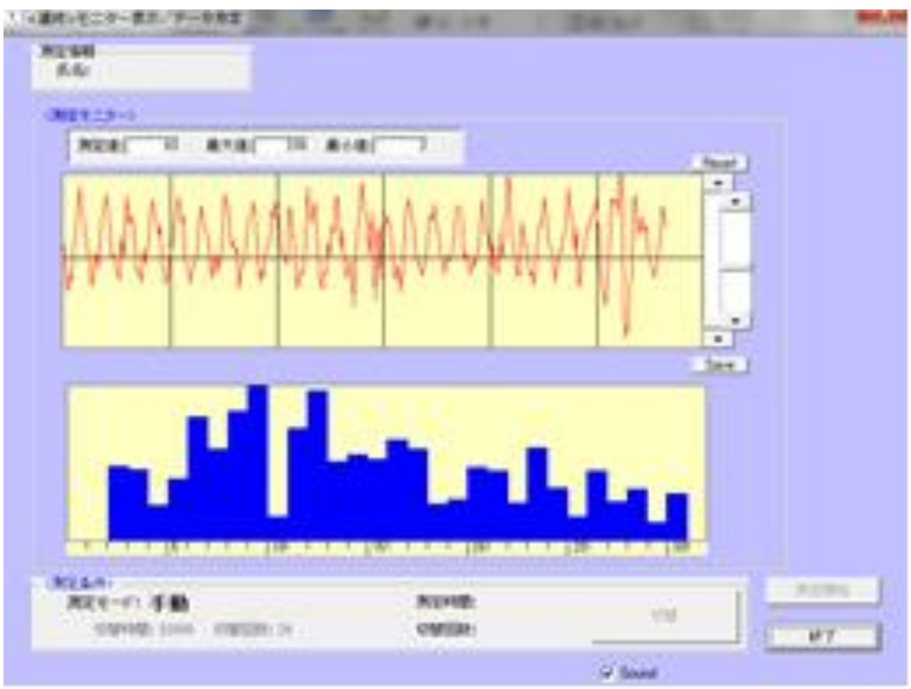


Fig. 5 PC screen display during EEG measurement.

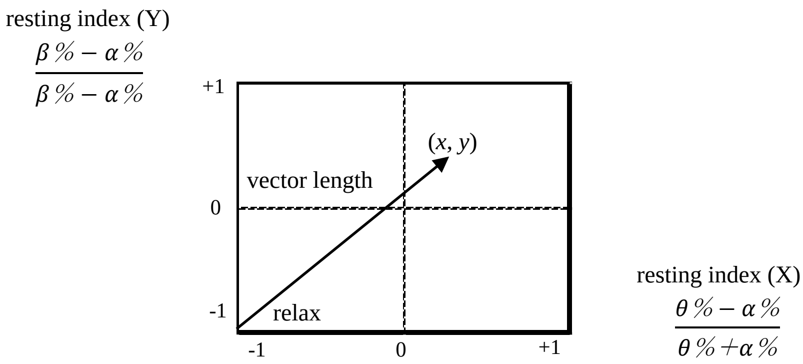


Fig. 6 Conceptual drawing of the resting index.

The EEG is quantified by analysis software, based on the respective numbers of wave appearances over the entire EEG per frequency (every second and every 1 Hz frequency). The resting index is defined as the ratio of the α wave appearance rate to the overall EEG wave appearance rate [12]. The resting index decreases when the number of α wave appearances increases and increases when the number of α wave appearances decreases.

2.3 Definition of the Resting Index and Overview of the EEG Measurement

The EEG is quantified by analysis software, based on the respective numbers of wave appearances over the entire EEG per frequency (every second and every 1 Hz frequency). The resting index is defined as the ratio of the α wave appearance rate to the overall EEG wave appearance rate. The resting index decreases when the number of α wave appearances increases and increases when the number of α wave appearances decreases (Fig. 6) [15].

The influence of all stimuli is reflected in an EEG. When a person is walking, for example, the EEG is affected by vibration and the movement of their line of sight. The brain responds not only to the stimulus caused by the measurement target. However, we here sought to assess only the influence of the specific measurement location, eliminating the influence of other stimuli. To this end, we employed a “measurement protocol” based on the study context. More specifically, we unified the factors other than the influence of the respective measurement locations, and designed a measurement plan that eliminated these extraneous factors as much as possible. In addition, as α waves are also generated by drowsiness, we ensured that the measurement eliminated the influence of drowsiness. Fig. 7 summarizes the measurement protocol created for the study.

As shown in Fig. 7, a subject first sat in a chair to eliminate the effect on the EEG due to walking. Next, they activated brain activity by doing simple mental arithmetic. Then, they gazed at the landscape of the respective measurement location, and then watched a video on a PC, which was used to fix the movement of

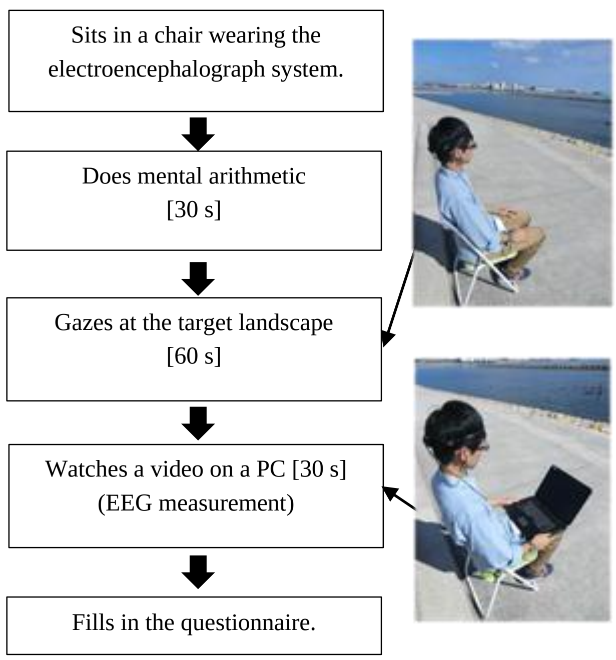


Fig. 7 Measurement protocol (measurement procedures).

their line of sight. In this study, the subject's EEG was recorded as they viewed the scenery through a train window.

The same procedures were followed in the seaside and road spaces, but as it was necessary to eliminate the influence of fatigue and drowsiness, we also obtained a control value before and after each on-site observation, by measuring their EEG in a room. Table 1 shows an overview of the EEG measurement in the study, including the measurement dates and weather conditions. And, the basic concept of Akashi City, where the study survey was conducted, refers to the sea and other rich natural environments of the city as regional characteristics. The coastline is a vital regional resource for Akashi City, and this study selected a seaside space to assess the healing and relaxation effects, because the seaside is a typical outdoor location for the residents' daily activities and relaxation. To measure the EEG control value before and after the on-site survey, we used a school room, where the external stimuli were relatively small. Fig. 8 shows the survey routes for the EEG measurement and questionnaire surveys in this study.

Table 1 Overview of EEG measurement.

Date of survey	Weather	Highest temperature	Humidity	Time of observation
November 9, 2013	Sunny	20.3 ℃	42%	
December 17, 2013	Cloudy	11.2 ℃	51%	
December 19, 2013	Sunny	10.9 ℃	67%	9:30-16:00
December 21, 2013	Sunny	10.4 ℃	66%	
January 18, 2014	Sunny	8.6 ℃	50%	
January 23, 2014	Sunny	9.9 ℃	57%	
Total number of subjects: 16 people (university sophomore, 20 years old)				
Average research time per person: about 3 h				

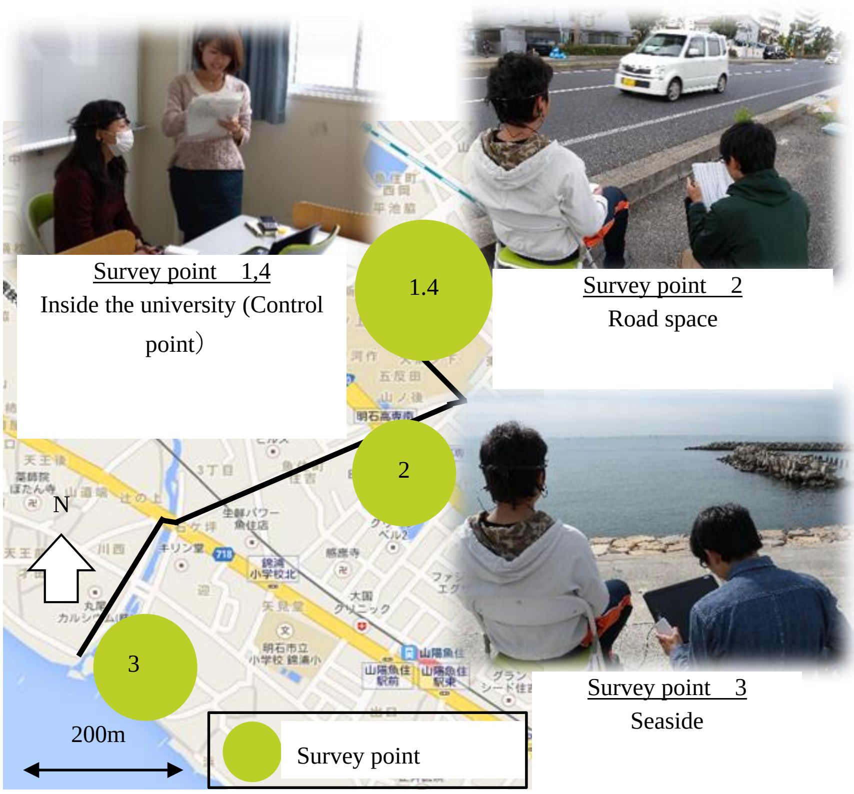


Fig. 8 EEG measurement route and locations.

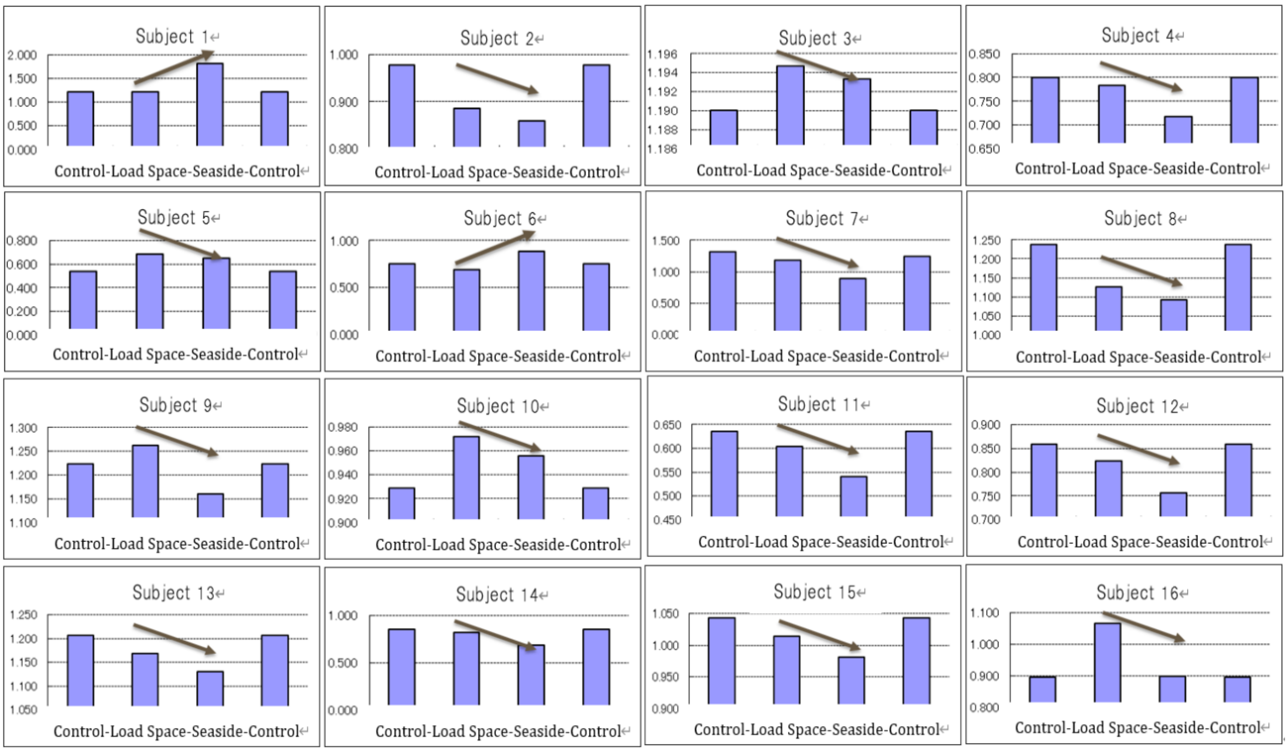


Fig. 9 Results of EEG measurement (vertical axis: Stress level; horizontal axis: Control-Load space-Seaside-Control).

Table 2 Adjective pairs for the SD method.

Clear	—	Neither	—	Hazy
Healing	—	Neither	—	Not healing
Monotonous	—	Neither	—	Complex
Quiet	—	Neither	—	Noisy
Static	—	Neither	—	Dynamic
Light	—	Neither	—	Dark
Natural	—	Neither	—	Artificial
Wet	—	Neither	—	Dry
Like	—	Neither	—	Dislike
Soft	—	Neither	—	Hard
Charming	—	Neither	—	Dull
Open	—	Neither	—	Closed
Refreshing	—	Neither	—	Gloomy
Lively	—	Neither	—	Lifeless
Relaxed	—	Neither	—	Nervous
Sober	—	Neither	—	Flashy
Calm	—	Neither	—	Restless
Plain	—	Neither	—	Picturesque
Round	—	Neither	—	Straight

2.4 Overview of the Questionnaire Survey

In the study, a questionnaire survey was conducted after completion of the EEG measurement in the road and seaside spaces, to compare the questionnaire results with those of the EEG (Fig. 7). The questions in the questionnaire were of two types: (1) a direct question asking the subject what level of stress they felt in the EEG measurement location (Very stressful; Neither; Very relaxed); and (2) an indirect question eliciting information on the subject's spatial cognition of the EEG measurement location, using 19 adjective pairs (Table 2).

3. Results

3.1 Results of the EEG Measurement

Fig. 9 shows the results of the EEG measurement in the seaside and road spaces, as well as the control values measured in the school room. As shown in Fig. 6, the lower the resting index value was, the more relaxed the subject felt. From Fig. 9, we can see that 14 out of the 16 subjects (excluding Subjects 1 and 6) were more relaxed in the seaside space than in the road space. The control value was adjusted so that the measurement values before and after the on-site observation would be equal, in order to eliminate the influence of fatigue and drowsiness on the brain waves.

3.2 Questionnaire Survey Results

After the EEG measurement, we conducted a direct questionnaire survey, asking the subjects the degree of stress they felt in the EEG measurement location, with five possible responses: very stressful, stressful, neither, relaxed, and very relaxed. Table 3 shows the questionnaire results for the road space, and Table 4 shows those for the seaside space.

As shown in Tables 3 and 4, while all subjects answered that they were relaxed in the seaside space, while 14 out of the16 subjects answered that they felt stress in the road space.

3.3 Results of Factor Analysis Using the SD Method

We also conducted a factor analysis using the results obtained by the questionnaire survey. The purpose of factor analysis is to clarify the data structure when a large amount of data is obtained, by extracting and interpreting the common factors contained in the data.

Table 5 shows the results of the factor analysis: the eigenvalues and cumulative contribution rates. As the Table 5 shows, when the number of factors is 2, the eigenvalue is more than 1, and the accumulated contribution rate is more than 70%. We thus set the number of factors to 2 when performing the factor analysis. Table 6 shows the factor loadings after the varimax rotation. Based on Table 6, this study named

Factor 1 “Artificial stress”, and Factor 2 “Gorgeous axis”. Fig. 10 shows a graph of the factor scores, with Factor 1 as the *y* axis and Factor 2 as the *x* axis. The factor scores may be roughly classified into three groups viz. Factor 1, with the road space and seaside space divided into different groups across the “artificial stress axis”. On the other hand, focusing on the “picturesque axis”, there were no clear differences in the factor scores, with broad variance observable.

Table 3 Questionnaire results for the road space.

	Number of respondents	Shares
Very stressful	3	18.8
Stressful	11	68.8
Neither	2	12.5
Relaxed	0	0
Very relaxed	0	0
Total	16	100.0%

Table 4 Questionnaire results for the seaside space.

	Number of respondents	Shares
Very stressful	0	0%
Stressful	0	0%
Neither	0	0%
Relaxed	9	56%
Very relaxed	7	44%
Total	16	100.0%

Table 5 Eigenvalues and cumulative contribution rates.

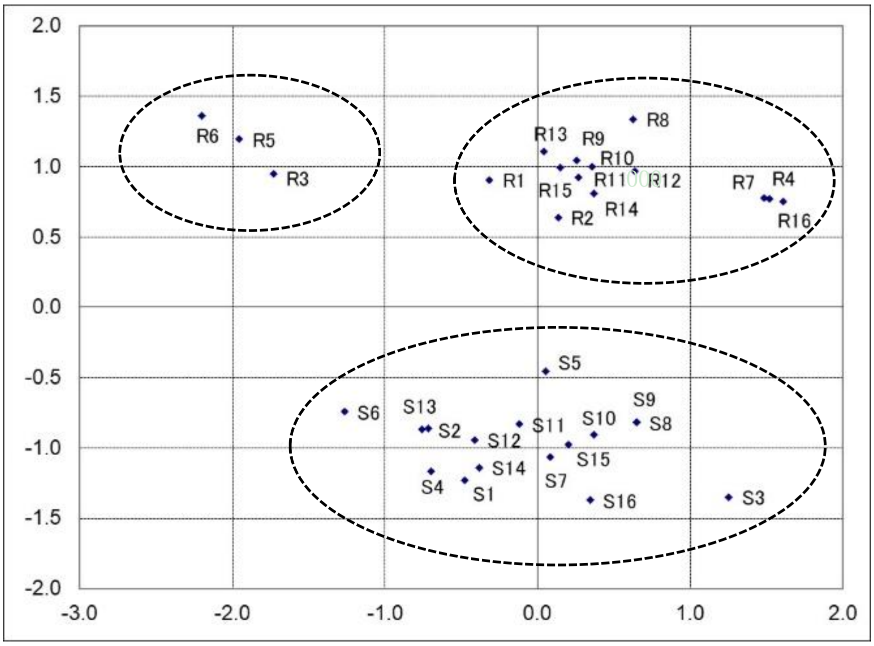
Factor No.	Eigenvalue	Contribution rate	Cumulative Contribution rate
1	13.37	66.86%	66.86%
2	1.02	5.11%	71.97%

Table 6 Factor loadings for each adjective pair.

Adjective pair	Factor 1	Factor 2
Natural-Artificial	0.9824	0.0729
Clear-Muddy	0.9766	-0.0062
Static-Dynamic	0.9599	0.0414
Relaxed-Nervous	0.9526	-0.0451
Healing-Not healing	0.9523	0.0493
Quiet-Noisy	0.9427	0.0924
Refreshing-Gloomy	0.9256	0.2053
Soft-Hard	0.9206	0.042
Like-Dislike	0.8578	0.2145
Charming-Dull	0.8355	0.0377
Light-Dark	0.8113	0.2375
Calm-Restless	0.8068	0.0426
Open-Closed	0.7904	0.2802
Monotonous-Complex	0.7374	0.1913
Wet-Dry	0.6944	0.4178
Curved-Straight	0.6534	0.2179
Sober-Flashy	0.08	0.8787
Lively-Lifeless	-0.4194	0.0313
Plain-Picturesque	0.0013	0.0748

Factor 1

artificial stress axis



Factor 2 gorgeous axis

R (Road space) Subject No., S (Seaside) Subject No.

Fig. 10 Factor score.

4. Discussion

4.1 Relationship between the EEG and As Reviewer Pointed Out, I Revised the Questionnaire Survey to Factor Analysis Results

Fig. 9 shows that 14 out of the 16 subjects (roughly 88%, excluding Subjects 1 and 6) were more relaxed in the seaside space than in the road space. As shown in Table 4, all 16 subjects (100%) answered that they were "(very) relaxed" in the seaside space; whereas, as Table 3 shows, two subjects answered "Neither", and the remaining 14 subjects (roughly 88%) answered that they were "(very) stressed" in the road space. In the case of Subject 1, whose EEG measurement results showed a more relaxed state in the road space than in the seaside space, he/she answered "stressed" in the road space and "relaxed" in the seaside space in the questionnaire. Subject 6 answered "neither" in the road space and "relaxed" in the seaside space. Both subjects showed a different questionnaire result to that of the EEG measurement.

After the EEG measurement, we asked Subjects 1 and 6 about their physical condition, and both answered that they were suffering a lack of sleep due to a cold, suggesting that the measurement protocol for eliminating the influence of fatigue and drowsiness on the survey had not functioned well. However, in the case of the other 14 subjects, roughly 88% of the total subjects, the EEG measurement results were consistent with the questionnaire results.

4.2 Relationship between the EEG and the Factor Analysis Results

Focusing on the artificial stress axis in Fig. 10, all the subjects felt stressed in the road space but relaxed in the seaside space. This means that the factor analysis results were also opposed to the EEG measurement results for Subjects 1 and 6, who showed a more relaxed state in the road space than in the seaside space in the EEG measurement results. Although two subjects answered "neither" for the road space in the questionnaire, the factor analysis results were roughly consistent with the questionnaire results, where the degree of stress was inquired into directly. Regarding the picturesque quality, three Subjects (3, 5, and 6) answered that the road space was "sober and lifeless", showing some variation in the subjects' impressions of the road space. In Fig. 10, subjects who found the seaside space relaxing, based on the factor analysis results, were on the negative side of the artificial stress axis. However, the subjects were dispersed almost evenly, on both the positive and negative sides of the picturesque axis.

5. Conclusion

The on-site EEG measurement results showed that roughly 88% of the tested subjects (14 of 16) were more relaxed in the seaside space than in the road space. In the questionnaire survey conducted simultaneously with the EEG measurement, all the subjects (16 of 16) answered that they felt more relaxed in the seaside space than in the road space, showing some discrepancy with the EEG results. However, as there was, overall, a high correlation between the EEG and questionnaire results, we may conclude that the EEG-based method is an effective form of spatial perception assessment. The reason for the abovementioned discrepancy would appear to be that the physical condition of the two subjects in question (1 and 6), was subpar on the measurement day, and thus the measurement protocol did not function effectively. In addition, the subjects who felt "relaxed" in the seaside space tended to be dispersed almost evenly on both the positive and negative sides of the picturesque axis.

Some related future challenges are as follows.

(1) For improvement in the survey and verification accuracy, the reliability of the survey data must be increased by incorporating a greater number of measurement days and subjects, and including subjects from various generations.

(2) The on-site survey locations in the study were a crowded road space, and a seaside space whose healing and relaxing effects had been confirmed in previous studies. We selected contrasting locations to verify the different degrees of locational stress. However, in future, survey spaces with a greater variety of characteristics must be selected, to improve the accuracy and detail of the utility assessment of the EEG-based method.

This study considers these to be follow-up tasks of the present study, which will increase the accuracy and detail of our analysis and verification.

Acknowledgment

I am very grateful for the cooperation of Mr. Akio Kimura of Digital Medic Co., Ltd., in the research and analysis in this study. And this study was supported by JSPS KAKENHI Grant Number 17K14751, Grant-in-Aid for Young Scientists (B).

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