Comfort Evaluation from EEG Dipole Imaging

Yuna Shigematsu, Yuta Ueji and Atsushi Ishigame
Graduate School of Engineering, Osaka Prefecture University, 1-1, Naka-ku gakuen-cho, Sakai, Osaka

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Abstract: Different people may have different feelings even in the same environment. However, most of the evaluation index in comfort are based on a fixed standard without considering individual differences. In this study, we focus on the preference of comfort, and discussed the dipole imaging of brain waves to evaluate the comfort. The amygdala is said to be one of the parts of the brain related to comfort. In this paper, we stated the relationship between comfort and the area around the amygdala by dipole imaging.

1 INTRODUCTION

For humans, it is important to prepare an environment where they spend a lot of time on a daily basis to lead a comfortable and healthy life. If environmental comfort can be improved, it can play a major role in improving quality of life, and further improve learning efficiency and work productivity (Vernon, 1919).

Depending on the surrounding environment, we have various feelings such as heat cold, glare, and noisiness as shown in figure 1. In addition, different people may have different feelings even in the same environment due to individual differences, gender and age differences. Thus it is necessary to provide each individual with an appropriate environment so that everyone can have a comfortable life.

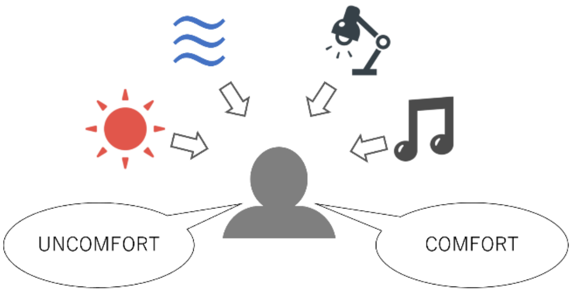

Figure 1: Conceptual diagram (Feeling comfort).

Most of the evaluation index are based on a fixed standard without considering individual differences. When it comes to a thermal environment, it is evaluated by 4 environmental elements (the indoor temperature, humidity, air flow velocity, radiation) and 2 human body elements (human clothing amount, metabolism). By using these, we evaluate a thermal environment such as WBGT (Wet-Bult Globe Temperature) for environmental elements, PMV (Predicted Mean Vote), SET (Standard New Effective Temperature), for human body elements. These index are created based on the rule of thumb and the questionnaire, which is a type of the subjective evaluation.

The method using brain information can be mentioned as a method of considering individual differences. Research focusing on the brain, which controls the majority of biological reactions, requires expensive equipment. So those research was focused on reports of applications in the medical field such as epilepsy and sleep disorders. However, in recent years, with the sophistication and price reduction of devices, we have been actively researched on human sensation by measuring brain function.

There are various types of devices that measure brain function, such as MRI (Magnetic Resonance Imaging), MEG (Magnetoencephalography), fNIRS (functional Near-Infrared Spectroscopy), and EEG (Electroencephalogram). MRI and MEG have high spatial resolution as a merit, but they have low time-resolving ability and restrain the body. On the other hand, although NIRS and EEG have the disadvantages that the measurement site is rough due to the low spatial resolution and it is difficult to measure deep brain, the device is simpler than MRI and MEG, and can measure simply covering the subject with a headgear-like device without restraint of the body (Teodore, John, Greg, Dennis, Jose,

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2009). For this reason, we evaluate comfort considering individual differences with EEG in this paper.

The amygdala is one of the parts of the brain related to comfort, and it is said that the amygdala is excited in an uncomfortable state. In this paper, we infer that there is a difference around the amygdala by using EEG when comfortable and uncomfortable.

Frequency analysis is mainly used for EEG analysis. However, detailed analysis can be difficult due to the complexity of brain function. In addition, EEG has a high temporal resolution, but has a low spatial resolution. Therefore, it is difficult to directly identify the electrical activity in the brain. Thus, in this study, we decided to use dipole imaging to identify the signal source by estimating the equivalent dipole signal intensity distribution on the virtual surface in the brain from the scalp potential. Then, we hypothesized that comfort can be evaluated from the difference around the amygdala when comfortable and uncomfortable by using dipole imaging. To test this hypothesis, we conducted an experiment showing images that give comfortable feelings and uncomfortable feelings, and analyzed EEG by dipole imaging. By proving this hypothesis, we reveal that comfort can be evaluated from amygdala information by dipole imaging.

By further applying this, it is possible to consider individual differences in a comfortable environment for the current control of the environment such as air conditioning and lighting. By adding the comfort evaluation index that takes individual differences into consideration as the element of environmental control, we perform environmental control that takes into consideration differences in comfort due to differences in gender, age, amount of exercise, and the situation that was placed until just before. By doing so, we can create a comfortable environment that suits each situation, and we believe that we can improve QOL, reduce fatigue, and improve productivity accordingly.

2 COMFORT AND DISCOMFORT

Comfort and discomfort are one of the most basic psychological attributes for understanding behavior, and it approaches a stimulus that causes pleasure but tries to move away from a stimulus that causes discomfort.

The amygdala is an important component of the limbic system located inside the temporal lobe. The amygdala is thought to play a central role in controlling emotional behavior (Olds and Milner, 1954; Klüver and Bucy, 1937). It is expressed in determining the behavior by judging the external situation by judging whether it is advantageous for the survival of the individual, the maintenance of the species or not, and specifically the autonomic nervous function, awakening, sleep, and attention. It is considered to have a decisive influence on the regulation of motor control. The amygdala is agitated when it becomes psychologically burdensome such as an unpleasant scene. The prefrontal cortex suppresses amygdala excitement, but if the load continues to occur, the amygdala remains agitated, resulting in increased blood pressure and insomnia. By touching the body, it is synthesized in the hypothalamus, and oxytocin is secreted from the pituitary gland, whereby the amygdala excitement can be sedated.

3 EEG ANALYSIS

The brain is a group of innumerable nerve cells, which is said to have 14 billion cells, and is said to be the highest center that not only controls human thoughts and behaviors but also controls their emotional and autonomic functions. Nerve cells communicate with each other by weak electricity via dendrites emerging from them. This phenomenon occurs in the pyramidal cells of the cerebral cortex, and their electrical activities are superimposed on each other and transmitted to the surface of the head. The EEG is a measurement of this transmitted electrical activity.

3.1 Source Imaging

The electroencephalogram is an effective method to elucidate the brain function in an environment close to nature because the measurement environment is not limited and can be easily measured non-invasively. However, the spatial resolution of EEG is low due to the limited number of electrodes and the low conductivity of the skull. Therefore, it was difficult to identify the electrical activity in the brain directly from the potential distribution on the scalp surface. As a method to solve this problem, brain dipole imaging has been proposed in which the equivalent dipole signal strength distribution on the virtual surface in the brain is estimated from the scalp potential and the signal source is specified. According to this method, the signal source generated in the brain can be equivalently expressed by the distribution of multiple dipole signal intensities on the virtual surface in the brain, without being limited in the number and direction. The solution to this inverse

EEG problem is affected by noise due to measurement and errors in the transfer matrix caused by distortion during model design. The measurement noise is caused by measurement environment such as electrode impedance and artifacts such as blink and body movement. On the other hand, the error of the transfer matrix is caused by the distortion in the model design such as the displacement of the electrode attachment position, the individual difference in the head shape, and the variation in conductivity. Therefore, it is important to consider the influence of noise in the solution of the inverse EEG problem, due to estimate brain dipole imaging with high accuracy (Rush and Driscoll, 1969; Ary, Klein and Fender, 1981; Salu, Cohen, Rose, Sato, Kufta, and Hallett, 1990).

3.2 Event-related Potential

Among the observed EEGs, those that spontaneously and continuously appear on spruce are called background EEG. Background EEG occurs because the activity of neurons on the surface of the cerebral cortex is constantly occurring throughout the cortex. On the other hand, the brain potential that occurs after stimulation of receptors and events related to psychological processes such as perception, attention, cognition, and memory is called event-related potential (ERP). Since ERP is a minute potential change of about 0.1 μV to several tens of μV compared with the background EEG, multiple waveforms measured under the same conditions are arithmetically averaged to identify the ERP component. In addition, the positive wave that appears at about 300 ms is called P300 among ERP (Sidman, Ford, Ramsey and Schlichting, 1990). P300 is thought to be involved in stimulus comparison, evaluation, judgment, selective attention, and cognitive context updating.

4 VERIFICATION EXPERIMENT ON THE COMFORT EVALUATION

4.1 Experiment Outline

As described in the previous section, the authors believe that there is the difference of comfort and discomfort in the amygdala using EEG source imaging. To verify the hypothesis, we conducted an experiment to show images that are thought to give comfortable and uncomfortable feelings to the subject. We show a conceptual diagram of the experiments in Figure 2.

For the subject, 10 comfortable images and 10 uncomfortable images (20 in total) specified by GAPED (Details explain in Chapter 4.2) were randomly displayed for 3 seconds each. Figure 3 shows the examples of the displayed image. The procedure was performed for 10 times. We show the flow of the experiment in Figure 4.

Figure 2: Conceptual diagram of the experiments.

(a) (b)

Figure 3: The examples of the displayed image. (a) The example of the comfortable image (b) The example of the uncomfortable image.

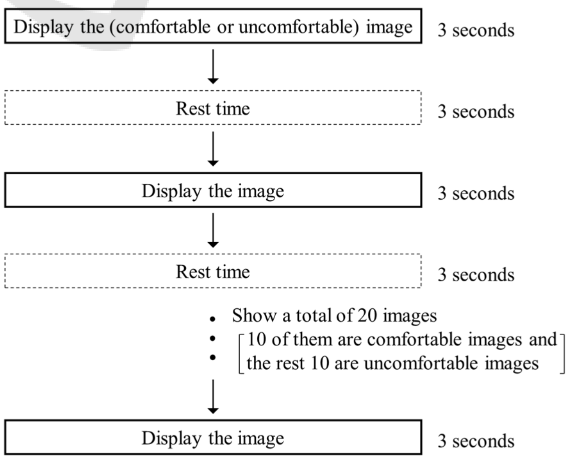

Figure 4: The flow of the experiment.

4.2 Used Equipment and Measuring Method

The used instruments were as follows.

-Electroencephalogram measurement system
EMOTIV EPOC+ (14 Channel)
Figure 5 shows EPOC+ used in the experiment.

Figure 5: EMOTIV EPOC+.

-GAPED(The Geneva Affective Picture Database)
A Database of emotional visual stimuli. Those with great valance and dominance and little arousal are comfortable images, and the opposite is uncomfortable images (Dan-Glauser and Scherer, 2011).

The measured EEG was averaged to remove the influence of background EEG. Then it was analyzed by the method described below for the measured brain waves.

-Dipole imaging

To evaluate the comfort state of the subject, we determined the content of the dipole imaging(Cuffin, 1998).

A head model is set to estimate the signal intensity distribution in the brain from the scalp potential. Head models include sphere models, FEM (finite element model)(Awada, Jackson, Williams, Wilton, Baumann and Papanicolaou, 1997), and BEM(boundary element model)(Fuchs, Drenckhahn, Wischmann and Wagner, 1998.). However, since BEM and FEM require MRI images of each individual, the head model is the one-layer sphere in this study as shown in Figure 6 (Baillet, Mosher, Leahy, 2001).

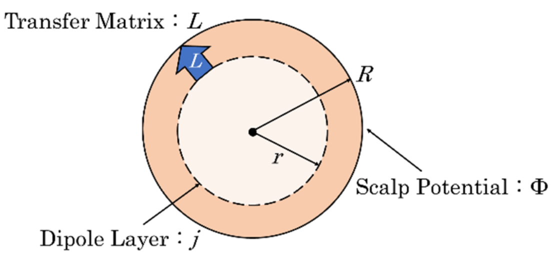

Figure 6: Head model.

A dipole layer was virtually placed in the brain of this head model. On this layer, multiple dipole signal sources in the radiation direction were installed at equal intervals. The signal sources generated in the brain can be equivalently represented by dipoles on this layer, regardless of the number or direction. Using the transfer matrix L from this dipole layer to the scalp surface, the process of observing the scalp surface potential Φ was modeled by the following equation.

$$\Phi = \mathrm{L} \cdot \mathrm{j} + \mathrm{n} \tag{1}$$

j is the dipole signal strength distribution and n is the noise. The transfer matrix L is determined by the shape of the head model, conductivity, and electrode placement.

That equation is a forward problem for dipole imaging, and solve this inverse problem. In this study, we solved the inverse problem by mne (minimum norm estimation) as in the following equation (Pascual-Marqui, 1999; Gramfort, Luessi, Larson, Engemann, Strohmeier, Brodbeck, Goj, Jas, Brooks, Parkkonen, Hämäläinen, 2013).

$$\min ||\Phi - \mathrm{Lj}||^2 \tag{2}$$

5 RESULT

5.1 Simulation Result

The result of simulation by dipole imaging is shown in Figures 7 and 8. Figures show the parietal hemisphere after normalizing the dipole signal intensities to size 1. The upper part shows the frontal region. Looking at Figures 7 and 8, there is a strong dipole only in the simulation result at the time of discomfort in the right central part (Broken line area), that is, around the amygdala. That is, it is considered that the signal source exists around the amygdala only when the user is uncomfortable.

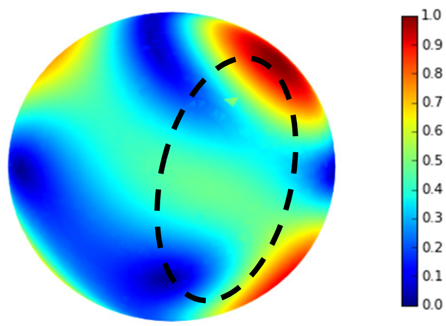

Figure 7: Simulation result (Comfortable images).

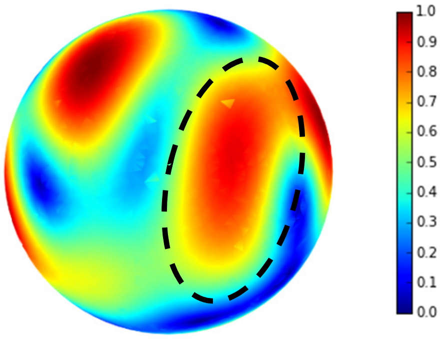

Figure 8: Simulation result (Uncomfortable images).

5.2 Discussion

From the results of this simulation, there was a difference between the presentation of comfortable images and the presentation of uncomfortable images. When the uncomfortable image was presented, the source signal was seen in the right central part, that is, around the amygdala. However, in this study, the results of the comfort image presentation and the uncomfortable image presentation are added and averaged to remove noise. Looking at the simulation results for each image, there were cases where the source signal was found around the amygdala even when the comfort image was presented, and no signal source was found around the amygdala even when the uncomfortable image was presented. Figure 9 shows the simulation result when a certain uncomfortable image is presented.

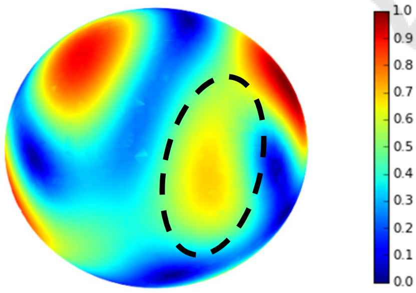

Figure 9: Simulation result (A certain uncomfortable image).

According to this result, a weak reaction is seen around the amygdala, but the reaction is not strong enough to be called a signal source. From this, it is considered that the accuracy that can be evaluated in consideration of individual differences, which was the initial objective, has not been reached the level at which individual comfort evaluation can be performed in consideration of individual differences. As a method for improving the accuracy, there is an improvement of the head model. This time, a single-layer sphere model was used as the head model. There are various things such as the skull and the brain in the head and it is not uniform. Therefore, we use a three-layer sphere model in which the conductivity of the scalp, the skull, and the brain are separately set (Sidman, Ford, Ramsey and Schlichting, 1990). It is possible to perform imaging in consideration of noise caused by the scalp and skull, and it is considered that the accuracy can be further improved. In addition, we used mne as the solution of the inverse problem. However, when mne is used, the current value may be estimated over a wide range. Therefore, it is considered that the accuracy of the signal source can be further improved by using another method such as MCE (minimum current estimation), LASSO (least absolute shrinkage and selection operator), or hierarchical variational Bayes estimation method.

6 CONCLUSION

In this paper, we examined the evaluation of comfort and discomfort using dipole imaging. We presented images that gave comfortable and unpleasant emotions, and analyzed them using EEG dipole imaging. As a result, it was found that the source signal was found around the amygdala when the uncomfortable image was presented. By adding the proposed comfort evaluation index, that takes into account individual differences, for environmental control such as air conditioning and lighting as an element of environmental control, we can control the environment according to the differences in gender, age, amount of exercise, and the situation that was placed until just before. By doing so, we can create a comfortable environment that suits individual situations, improve QOL, reduce fatigue, and improve productivity accordingly.

Therefore, the goal is to evaluate comfort considering individual differences, the head model is changed to a three-layer sphere model, and the solution of the inverse problem is improved to improve accuracy.

In the future, we would like to verify whether the proposed comfort evaluation is practical. To that purpose, we would like to compare the currently used comfort evaluation indexes such as air conditioning, lighting, and noise with the methods that add the proposed method. And by adding the comfort evaluation index proposed as an element of environmental control such as air conditioning and lighting as an element of environmental control, we would like to create a comfortable environment that suits each individual.

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