1/f-LIKE FREQUENCY FLUCTUATION IN FRONTAL ALPHA WAVE AS AN INDICATOR OF EMOTION.

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Abstracts:

There are two approaches in the study of emotion in the physiological psychology. The first is to clarify the brain mechanism of emotion, and the second is to evaluate objectively emotions using physiological responses along with our feeling experience. The method presented here belongs to the second one. Our method is based on the "level-crossing point detection" method, which involves the analysis of frequency fluctuations of EEG and is characterized by estimation of emotionality using coefficients of slopes in the log-power spectra of frequency fluctuation in alpha waves on both the left and right frontal lobe. In this paper we introduce a new theory of estimation on an individual's emotional state by using our non-invasive and easy measurement apparatus.

Keywords: fluctuation, EEG, estimation of emotionality, non-invasive and easy measurement apparatus.

1. Introduction

Human-error and mental stress caused by psychophysiological dissonance between people and artificial environments have become a social problem. In order to solve this, from the position of human life engineering, we have aimed at the development of field application techniques and devices that evaluate mental conditions of a person such as the degree of stress and fatigue, or feeling of comfort in various kinds of daily situations.

We have already carried out the development of a non-invasive and easy measurement technique for evaluating brain activity. The apparatus introduced here is a simple brain wave rhythm monitor we developed for measuring the frequency rhythms of brain waves, by which we can estimate stress or feelings of comfort for products and environments. This monitor is now used in the evaluation of a baby massage in a maternity hospital or of the brain activity of persons in a nursing home.

We are also studying the use of functional MRI measurement to get data of brain activity[1] and studying emotional and cognitive process of the brain using a dipole analysis technique for event-related potential[2],[3],[4].

Here, we introduce our evaluation-method of an individual's emotional state by using our monitoring system and show an example of our recent works.

2. 1/f fluctuation

Fluctuation is a dispersion of values occurring on time series. When representing a fluctuation spectrum on the double logarithmic scale with the vertical axis for the fluctuation value (Spectral Density: SD) and the horizontal axis for the fluctuation frequency (f), there exist a functional relationship: $\log_{10}SD = \log_{10} f^{a}$ between SD and f.

The value of "a" indicates the characteristic of fluctuation. When a=0, SD has no connection with frequency f. In this case, fluctuation occurs at random. On the other hand, when $a<0$, fluctuation keeps a certain degree of correlation with past fluctuation as seen in the Markov linkage. In this case, SD decreases in reverse proportion to frequency f with a gradient "a" as the frequency increases. Here, 1/f fluctuation means that SD decreases with a gradient "-1", that is, $\log_{10}SD = \log_{10} f^{-1} = \log_{10} 1/f$ (Fig.1). 1/f fluctuation is not specific. We can see it in breeze flows, rivulet sounds, classical music and biological phenomena such as heart beat interval[5] or frequency fluctuation of alpha wave, and 1/f-like fluctuation can often be observed in relaxed and comfortable situations[6],[7],[8].

3. EEG fluctuation as an indicator of emotion

The human brain consists of the two cerebral

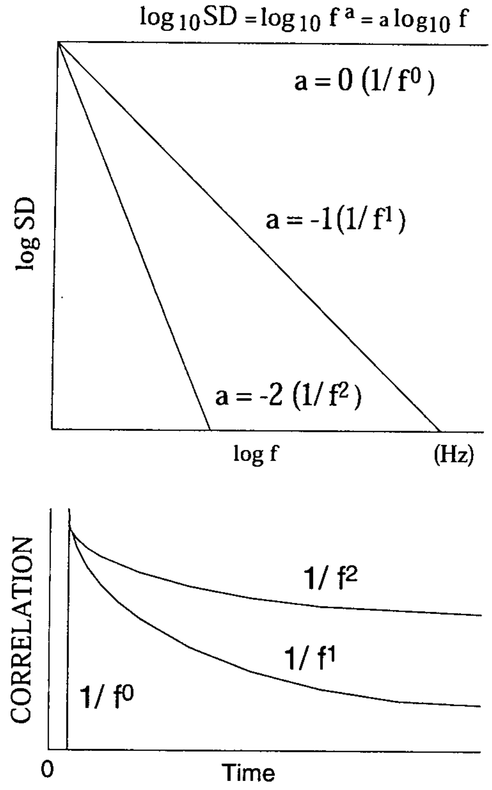

Fig.1 Relationship between Spectral Density and fluctuation frequency (the top figure) and correlation changes in time sequence (the lower figure)

hemispheres, brain stem, and cerebellum. The cerebral hemispheres have the center controlling higher order mental functions. Information related to emotion is processed in the hypothalamus in the upper portion of brain stem, and in the limbic system including the brain called the limbic cortex existing deep in the cerebral hemispheres. The information processing of higher-order feeling involves the prefrontal lobe of neocortex to a considerable extent. The control of arousal level that affects the intensity of feeling involves the hypothalamus and a system called a reticular activating system existing in the brain stem. Activities relating to brain waves have a close relation with these systems.

A recent report indicates that fluctuation of brain waves varies with changes in feeling or degree of arousal. Feelings are always changing (mood), and the time-course measurement of brain wave fluctuation is considered to be more suitable for examing mood-changes compared with the static approach to information processing as represented by evaluation of mean values in conventional practice.

4. Hemispheric asymmetry for emotions

A number of studies have examined the relationship between affective processes and hemispheric asymmetries. Many investigators have converged on the hypothesis of a right-hemisphere dominance in emotion processing. The parietal lobe in the right hemisphere has an especially close relation to the activation of an arousal system.

On the other hand, recent studies have suggested the importance of the anterior region in emotion processing. Davidson and his colleagues have studied the central asymmetries related to behavioral-related positive affects and withdrawal-related negative affects[9]. They have suggested from their clinical and laboratory observations that the left prefrontal cortex is a biological substrate of approach behavior and positive affect, whereas the right prefrontal cortex is a biological substrate of withdrawal behavior and negative affect[10]. These laboratory studies have suggested a relative change in the asymmetry of electrical activities in anterior, but not posterior, scalp locations.

Along with neurophysiological approaches, a psychological conceptualization of emotion has been developed. Most variance in emotional judgements can be accounted for within a two-dimensional affective space. The two dimensions, valence (positive-negative) and arousal (calming-arousing), is thought to represent basic strategic dispositions of the organism, broadly affecting the directions and intensity of all affective behavior.

Heller proposed an emotion model combining brain activity with two psychological dimensions of emotion.[11],[12] In this model, an asymmetry of anterior activation relates to valence and an activation of the right parietal area relates to arousal of autonomic nervous system. According to this model, negative emotion would be judged as follows:

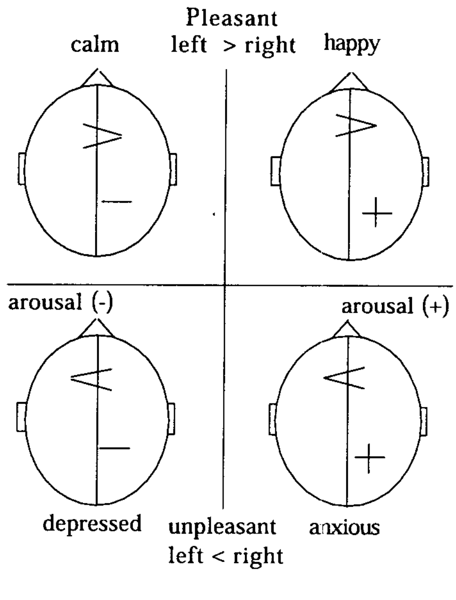

Fig. 2 Heller's emotion model

Anxiety is labeled negative valence and high arousal (activation of the right anterior region and the right parietal region), whereas depression is labeled negative valence and low arousal (an activation of the right anterior region but not of the right parietal region). Heilman proposed a similar model in terms of neural connections between the cortex and limbic system[13].

These models led to the idea that emotional experience involved specific patterns of neural activation. There are, however, some contradictions and there is room for further discussion with regard to relationship between the specified emotion and its neural activation.

5. Detection and analysis of the α wave frequency fluctuation

(1) measurement of brain waves

Brain waves comprise various frequency components in response to the conditions of the living body, and are continuously fluctuating. It is difficult to grasp the characteristics of brain waves by visual observation. One conventional technique for examining brain waves is to use a band pass filtering method to extract only a specific frequency component. In our apparatus, filtering, detection and analysis of fluctuation in brain waves are carried out using an experimental system shown in Fig.3.

(2) Detection of fluctuation characteristics

Brain waves are detected through a headband sensor in which exist two electrodes (Fpl and Fp2) and put on the forehead of human subject, as seen from Fig.3. The detected brain waves are transmitted to a note-type computer by a small EEG amplifier and digital-filtered to extract α-wave components (8-13Hz). Although both amplitude and frequency fluctuations are observed in extracted α-waves, focus is placed on only frequency fluctuation in the embodiment because amplitude shows significant differences among individuals.

Among the frequency components having passed through the digital band pass filter, only those having an amplitude greater than a given level (± 5 μV, as seen from Fig.3) are considered as α-waves.

The datum line is set in a given level of the electric potential fluctuations of the filtered wave, and rectangular pulse having a given potential are generated each time the wave crosses the datum line in a given direction (e.g. From negative to positive).

To calculate a time interval (cycle) for every consecutive pulse, the reciprocal of the resulting value is converted into the time series of instant frequency (i.e. Frequency is 1/cycle). When arranging the calculated frequency for every wave in the sampling order (in the order of elapsed time), frequency fluctuation in α-waves is extracted as a waveform consisting of points.

Based on the extracted EEG fluctuation data, fluctuation characteristics are analyzed. The time data recorded is divided into a number of unit times, and data are re-sampled at a constant time period within each unit time. Based on the unit data, a power level with respect to the fluctuation frequency is calculated via spectrum analysis using the FFT method. These processes are carried out because of the fact that spectrum analysis dose not produce constant time intervals among plots of changes in α-wave frequency converted into instant frequency, and to avoid a time lag between calculated and true sample lengths. More particularly, instant frequency time series is produced from the obtained time data by the following process.

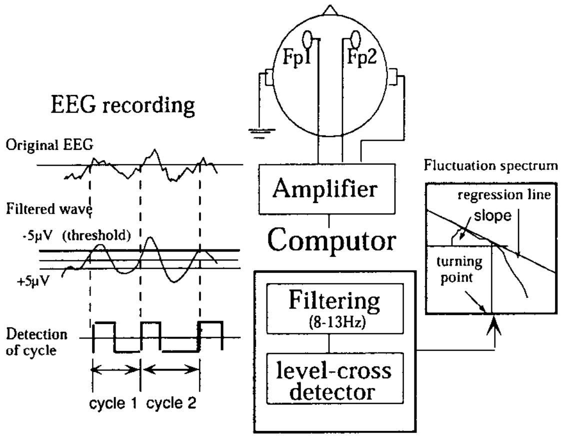

Fig. 3 The block diagrams on the analyzing process of frequency fluctuation in α-wave.

Frequency Fm at a sampling period Sm is letermined by the equation: $Fm = 1/\{P_{n+1} - \max(Pn)\}$
Under the condition of: $S_{m-1} < \max(Pn) \leqq S_m \leqq P_{n+1}$
Where the meaning of each of the letters is as follows.

Pn: generation time of the n-th pulse
S: sampling period
m: ordinal number
S_m: the m-th sampled period (determined by S*m)
Fm: the m-th sampled frequency
max.(Pn): the maximum value of Pn till the sampling period.

In this method, assuming that the sampling period is 50ms (20Hz), originally obtained time data are sampled without a sampling drop, and sample length (time interval) can be constant.

Then, from these time data, a tendency of changes in fluctuation spectrum with respect to fluctuation frequency is expressed in numerical values using the gradient of linear regression, so as to identify the characteristics of the changes. The fluctuation power value noticeably changes after passing over a certain frequency. After identifying that frequency over which the gradient changes (i.e. inflecting frequency), the frequency band is separated into two band widths with the boundary frequency, that is, low and high frequency band widths, each of which are regression-analyzed separately.

6. Estimation of emotion by the fluctuation-spectrum of α -wave

It is generally accepted that the psychological approach is mainly based on two pivotal parameters, positive-negative mood and feeling of arousal, as representing the emotional condition of individuals. It is preferable for the measurement of positive-negative mood to set these parameters as a common and basic item and to select additional evaluation items depending on stimulation.

In evaluation of the psychological condition of the subjects with the aid of the evaluation table, it is preferable to make an assessment before and after the physiological measurement, during both rest and experimental conditions as depicted by two sets of measurements.

Spectrum information of frequency fluctuation of α -wave (a slope coefficient of power spectrum shown in Fig.3) calculated for each individual is related to psychologically evaluated values of positive-negative mood and feeling of arousal to find correspondence between the values of fluctuation characteristics and psychological conditions.

From the experimental data in the last decade, we found that a slope representative of frequency fluctuation characteristic of the α -wave was correlated to an individual's feeling condition. In most cases, a slope coefficient is changed between 0 and -1. When a subject feels a negative mood and is highly aroused, the slope becomes lower (the coefficient is near 0 point, that is, the subject's rhythm of frequency fluctuation of α -wave is irregular), whereas the slope is near −1 (1/f) if the subject feels in a positive mood and is feeling lower arousal.

According to the results, we developed a non-invasive and easy measurement apparatus for the evaluation of mental conditions of a person in a given daily place. In addition to this, we proposed Yoshida's "basic affection vector model" for emotional conditions of individuals (Fig.4)[14]. In the model, an individual's feeling condition estimated from slope coefficients in frontal area (Fp1 and Fp2) is plotted in two psychological dimensions. The horizontal axis means "feeling of arousal" and the vertical axis means "positive-negative mood". There are two characters to this model. A first, this model is the oval consisted of long horizontal axis and short vertical axis. Secondly, the first or third quadrant of the oval is a distorting curve. In this model, a dimension of arrow vector represents the degree of comfortableness, and a vector direction expresses a location of basis affection. The angle and a dimension of vector line are calculated using two slope coefficients (Fp1, Fp2) as follows.

(1) Angle of a vector:
(2)
ATAN [{abs (Fp1 slope)-0.5}/ abs (Fp2 slope)-0.5}] (Unit: %)
0.5 means the center point between slope 0 and 1.

Generally a slope coefficient is near 0.5(abs) at rest condition.

(2) dimension of vector line:
(3)
dim. =[$\sqrt{}$ {(Fp1 slope)$*^2$+(Fp2 slope)$*^2$}/2]*100

A slope coefficient in the right frontal region (Fp2) correlates generally "feeling of arousal" and it in the right frontal region (Fp1) does "positive-negative mood". Fig.5 indicates the result of near 800 subjects measured in the experimental condition.

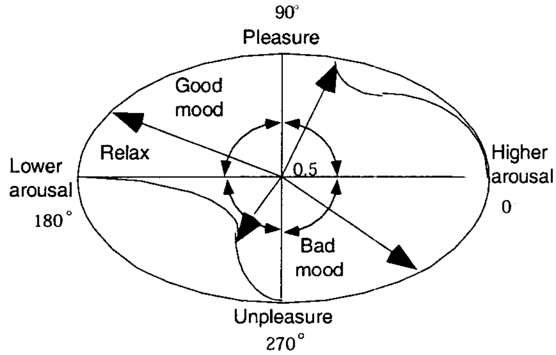

Fig.4 Basic affection vector model (Yoshida, 1999)

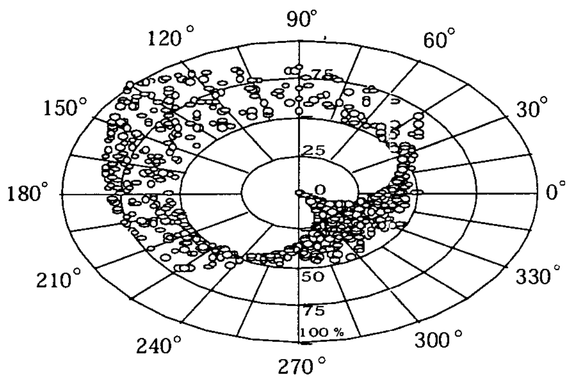

Fig.5 Distribution of comfortableness. Plotted points indicate each subject's dimension of vector.

7. Conclusion

Mental stress or comfort is connected to the feelings of individuals, and "positive-negative mood" is an important factor to know the essence of human beings. It is thus important to seek how to catch the feeling conditions objectively and quantitatively to live comfortably. In this paper we introduced a non-invasive and easy measurement technique for evaluating brain activity and an estimating method for an individual's emotion. We are sure that the 1/ f function of EEG will be a good indicator to evaluate our emotional condition.

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