Paper

Development of Biotelemetry Technique for EEG / ECG Measurement in a Strong ELF Electric Field

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To investigate the effects of Extremely Low Frequency (ELF; 50 - 60 Hz) electric fields on the human brain and nervous system, we developed a telemetry technique to measure the human electroencephalogram (EEG) and electrocardiogram (ECG) in a strong ELF electric field and at an alternating high potential. The telemetry system was developed well and the transmitters were small and light enough to measure EEG and ECG without stress. The feasibility of this technique was confirmed by the measurement in a strong ELF electric field. Thereafter, using this technique, the EEG and ECG were measured with nine subjects when they were exposed to a strong ELF electric field. The data were analyzed by FFT and the spectral powers of the EEG and the Heart Rate Variability were obtained. The preliminary results of the EEG and ECG analysis suggested the possibility of the biological effect from the strong ELF electric field exposure.

keywords: Biotelemetry, ELF electric field, EEG, ECG, Biological effect

1. Introduction

There has been an extensive study conducted on the biological effects of ELF electromagnetic fields(1-3). On the effects of an electric field exposure, for example, D.L. Hjeresen et al. showed the effects on avoidance behavior of rats(4) and swine(5) . B.W. Wilson et al. reported the effects on the melatonin level(6) . A.M.Coelho et al. showed the weak effects on the social behavior of baboons(7) . On the contrary, V.Margonato et al. showed that a 50 Hz electric field exposure, even of long duration at very high field strength, did not induce any harmful effects on tissues and did not impair the reproductive function of rats(8) . As to the effects on human biosignals, different results have been reported. In early studies, R.Hauf and others showed no effect on response time and EEGs(9,10) in weak field exposures. Later, L.Korpinen et al. also showed no effect on the pulse rate(11) . However, C.Graham et al. showed effects on response times and the event related potentials(12-13).

To investigate the biological effects of an ELF electric field, the quantitative analysis of human physiological functions is important. Non-invasive and ambulatory measurement has been required to measure the subtle change in physiological variables. Telemetry is one of the promising techniques to achieve this. However, it has not been easy to use telemetry technique to measure bio-electric signals in a strong electric field(14). We have developed a telemetry technique that enables us to measure an EEG/ECG at the body surface of the subject who is being exposed to an electric field even at a high electric potential.

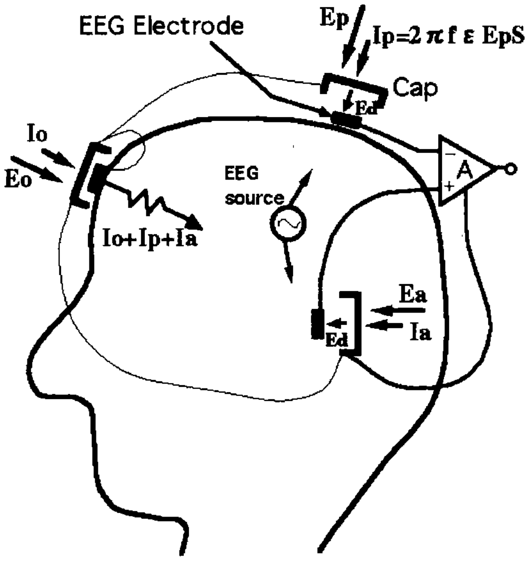

Fig.1 Principle of EEG measurement in a strong electric field.

2. EEG Telemetry

2.1 Measurement in an Electric Field Fig.1 shows the principle of EEG measurement. When a human body is exposed to a vertical ELF electric field, the electric field concentrates on the head of a subject. Therefore, with an ordinary technique, the EEG measurement is difficult due to the strong electric interference. In EEG measurement, an instrumentation amplifier is usually used to cancel out the effect of the interference. However, in the field exposure, a displacement current is induced in the body and a relatively large voltage is induced between the EEG electrodes. It is usually too large to be cancelled by the instrumentation amplifier for EEG measurement. To overcome this difficulty we have devised a technique to eliminate this interference. Conductive electrode caps were introduced for EEG measurement. The electrodes were fixed on the midline parietal (Pz) as a different electrode and on the left mastoid (A1) as an indifferent electrode. The ground electrode was positioned at the forehead (Fp). The caps were placed over each electrode to shield the electric field. It should be noted that this is not a simple shielding of the electrodes using the caps in electrical contact to the body surface. Instead, the caps were electrically insulated from the body surface by a coating. All the caps were connected with the ground electrode and ground line of the transmitter's circuits. In this way, the caps diminished and equalized the induced currents flowing into each different / indifferent electrode. Consequently, we could cancel the effect of induced current using an instrumentation amplifier, and measure the EEG without interference.

2.2 EEG Telemeter The EEGs were obtained and amplified by an instrumentation amplifier. After the signal was modulated in amplitude with the sub-carrier of 3 kHz, it was further modulated in frequency with the carrier of 31.2 MHz. To make the transmitter small, thin and light, coin-type Lithium cells were used and the circuits of the transmitter were built compactly.

The modulated and transmitted RF signal was detected and demodulated by a receiver (MVT-7100 YUPITERU). The signal that was modulated in the sub-carrier frequency was amplified and demodulated again into the EEGs by a rectifier and a low pass filter.

Fig.2 shows the appearance of the developed EEG telemetry system. The transmitter was light (26.5 g) and small (3 x 4 x 1 cm^3) enough to measure EEGs with little stress on the subject.

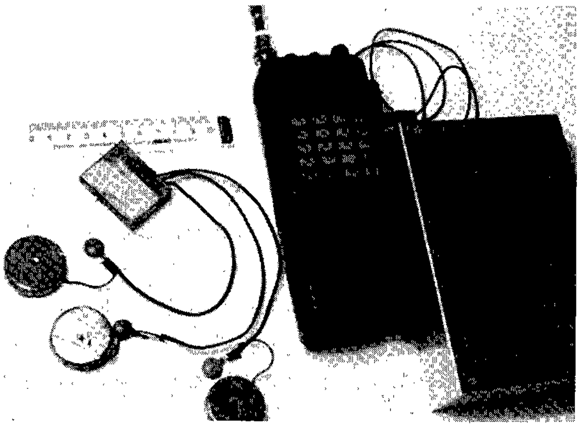

Fig.2 Appearance of a developed EEG telemetry system.

Table 1 Characteristics of the EEG transmitter.

Supply voltage	+/- 3 V
Current dissipation	23.8 mA
Carrier wave	Radio wave
Modulation mode	AM/FM
Carrier frequency	31.2 MHz
Sub-carrier frequency	3 kHz
Frequency range	2 - 45 Hz
Input impedance	22 MΩ
Input equivalent noise	0.5 μV
Linearity	1 %
Transmitting range	> 4 m
Dimensions	3.0 x 4.0 x 1.0 cm^3
Total weight	26.5 g

In the figure, we can see the conductive caps beside the EEG electrodes. Shielded wires were used to connect the electrodes. Table 1 shows the characteristics of the developed system. The input equivalent noise was small (0.5 μV) and the input impedance was large (22 MΩ) enough. Further, the bandwidth and the linearity were reasonable for the measurement of EEGs.

3. ECG Telemetry

3.1 Measurement in an Electric Field In a strong electric field, the ECG measurement is also difficult due to the strong interference mentioned above. Fig.3 shows the principle of ECG measurement. Telemeter circuits were installed in a conductive case that was a lidless box covered with conductive copper film. In this way, all the ECG electrodes were covered by the common case. The case contained all the electrodes attached on the left chest wall within a small area. The casing film was in electrical contact with the body surface, and it shielded the electrodes and the circuits from the outer electric field. Hence the device could detect ECG signals without strong interference. The transmitter was attached on the chest wall with a rubber band around the body.

3.2 ECG Telemeter The ECGs were obtained and amplified by an instrumentation amplifier. After the signal was modulated in amplitude with the sub-carrier of 3kHz, it was further modulated in frequency with the carrier of 18.8MHz. The circuits of the transmitter were built compactly.

The modulated and transmitted RF signal was detected and demodulated by a receiver (MVT-7100 YUPITERU). The signal which was modulated in a sub-carrier frequency was amplified and demodulated again into the ECGs by a rectifier and a low

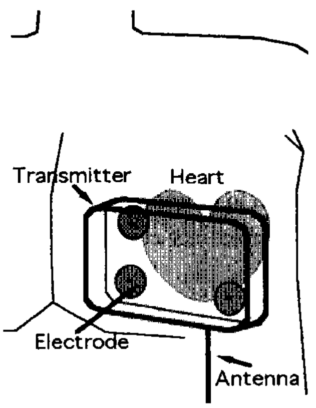

Fig.3 Principle of ECG measurement in a strong electric field.

pass filter.

Fig.4 shows the appearance of the developed ECG telemetry system. The transmitter was light (100 g) and small (11.4 x 8.0 x 2.5 cm^3) enough to measure ECGs with little stress on the subject. Table 2 shows the characteristics of the developed system. The input equivalent noise was small (1 μV) and the input impedance was large (1 MΩ) enough. Furthermore, the bandwidth and the linearity were reasonable for the measurement of ECGs.

4. Experiments

4.1 Experimental Condition In the experiment, a subject was exposed to a 50 Hz electric field using commercially available instrument designed for electric therapy. This device supply an alternating high potential (5 ~ 30 kV) to an electrode beneath the subject's feet.

Nine male volunteers (21 - 23 years old) participated in this study. Experiments were carried out from 1 p.m. to 6 p.m. in a laboratory. The room temperature and the humidity were 21 ~ 25 ℃ and 50 ~ 65 %, respectively. The ELF electric field was applied to subjects using a therapeutic device (Healthtron™) which was authorized by the Ministry of Health, Labor and Welfare in Japan and has been commercially available. With this instrument we could apply 30 kV to the soles of the feet of the subject through the PVC plate of a footstool. The grounded counter electrode was placed above the subject's head. As a result, the subject could be exposed to an electric field up to 300 kV/m(15,16).

4.2 Experimental Procedure Prior to the experiment, the procedure of the experiment and some effects of an ELF field exposure and the therapeutic device were explained to each subject, and his informed consent was obtained.

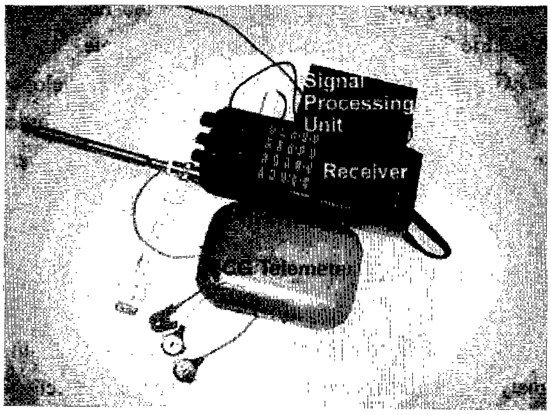

Fig.4 Appearance of the developed ECG telemetry system.

Table 2 Characteristics of the ECG transmitter.

Supply voltage	+/- 4.5 V (9 V)
Current dissipation	58.8 mA
Carrier wave	Radio wave
Modulation mode	AM/FM
Carrier frequency	18.8 MHz
Sub-carrier frequency	3 kHz
Frequency range	0.1 - 45 Hz
Input impedance	1 MΩ
Input equivalent noise	1 μV
Linearity	1 %
Transmitting range	> 6 m
Dimensions	11.4 x 8.0 x 2.5 cm^3
Total weight	100 g

Previous to the experiment, it was explained to the subject that the maximum duration of the field exposure would be less than 30 minutes. No more explanation was given on the duration and the timing of the field exposure in the session of measurement.

In regular use of the therapeutic device, the exposure was recommended to be within 30 minutes, and the maximum voltage was 30 kV. Therefore, the experiment was designed in the following manner. The time course of the experiment consisted of three sessions, i.e. 15 minutes rest, 30 minutes field exposure and 20 minutes rest periods. A subject equipped with the EEG/ECG transmitters sat quietly on the chair of the therapeutic device with his eyes closed. This condition in the first 15 minutes was considered to provide a control condition against the field exposure. The electric field was applied to the subject without any noticeable cue following the rest period. Then the electric field was switched off without any cue.

The EEGs/ECGs were measured using the developed telemetry systems and were recorded in a PCM data-recorder [NF Electronic Instruments : 5870]. The recorded data were sent to a computer (DEC PC/AT) and analyzed afterward.

5. Methods of Analysis

Fig.5 shows the time course of the experiment and the timing of data analysis. The data were divided into 7 analyzing sections (rest 1, rest 2, expo.1, expo.2, expo.3, rest 3, rest 4). Each of them consists of five and half minutes of data (65536 points).

The EEGs obtained from the electrode at the Pz position were processed after the measurement. In the Pz position, the components of major EEG wave bands can be detected of a fairly high level. Thus it was suitable for the evaluation of the vigilance level. The spectral power densities of the EEGs were calculated for each analyzing section by FFT. After the power densities of δ (0.4 - 4 Hz), θ (4 - 8 Hz), α (8 - 13 Hz) and β (>13 Hz) wave-bands were calculated, the amplitudes (power densities of $[\delta] + [\theta] + [\alpha]$) and the fast wave ratios($[\beta] / [\alpha]+[\beta]$) were obtained. They were considered to be one of the indexes of vigilance level[17].

In ECG analysis, the R waves were identified and the heart rate variability (HRV) was analyzed by FFT. The higher components (HF: 0.15 - 0.4 Hz) of the power spectral data were calculated to evaluate the activities of the parasympathetic nervous system. The lower components (LF: 0.04 - 0.15 Hz) were also calculated to obtain the ratio LF / HF which suggested the activities of the sympathetic nervous system[18].

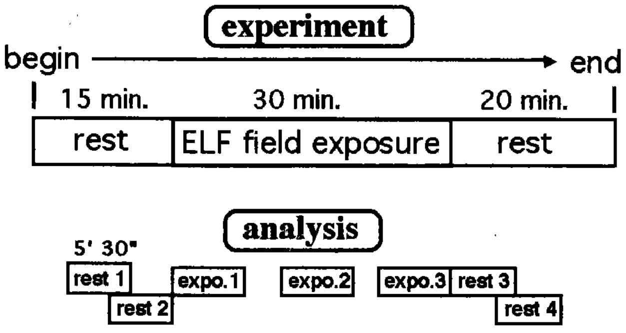

Fig.5 Time course of experiment and timing of data analysis.

6. Results of EEG Analysis

Fig.6 illustrates the EEG measured by the developed telemetry technique. It shows traces of the EEG before and during the strong ELF electric field exposure and at the alternating high potential. Alpha waves and beta waves could be observed reasonably well. With the developed technique, the EEGs were measured clearly even in the adverse condition of strong electric interference.

When a subject is exposed to a strong electric field, the body hair vibrates at the body surface not covered with clothes. To reduce the artifact due to the environmental physical interference such as the hair movement, white noise sounds (70 dB HL) and a fluctuating wind were applied to the subject to sustain his vigilance level. Fig.7 shows the variations of the normalized power of the EEGs before / after the electric field exposure. In this case, the data of six subjects were processed. The data of three subjects were not processed due to simple artifacts of initial measurement. The power density of each band was normalized by the value at the section "rest 2". The data were normalized in each subject to emphasize the change. No apparent difference was observed in each rest section. This suggested the vigilance level of the subject was kept almost constant over the rest sections. The power densities of EEGs decreased in the section of "expo.1", and eventually returned to the original level in the periods of field exposure.

Fig.8 shows the variations of the fast wave ratios and the amplitude of the EEGs. Each parameter was also normalized in the same way. In exposure periods, the fast wave ratios showed a slight increase. The amplitudes showed an apparent decrease. These results suggested the increase in the vigilance level.

Fig.6 Measured EEG signals in field exposure.

a) Before electric field exposure.

b) During ELF electric field exposure.

7. Results of ECG Analysis

Fig.9 shows the ECGs measured by the developed telemetry technique. The ECGs were measured clearly even in the adverse condition of strong electric interference. Some noise could be seen in the trace that might come from the incompleteness in the shielding and the electrode conditions.

With the ECG, the temporal change of HRV was analyzed. Noticeable changes were observed in the spectral power of HRV, particularly in the parameter LF / HF. Fig.10 shows the result. The ratio of the power in the "rest 4" period

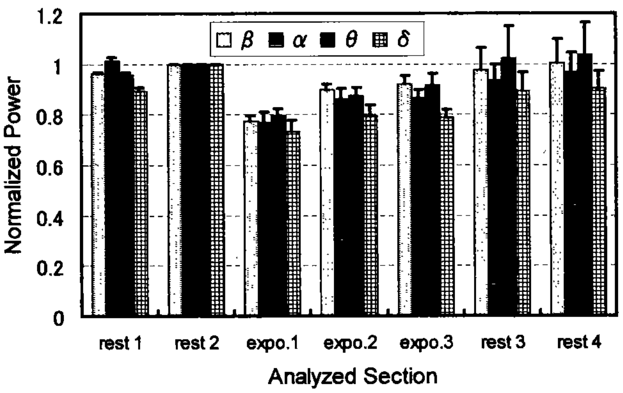

Fig.7 Variations of the normalized powers of the EEGs. (N=6)

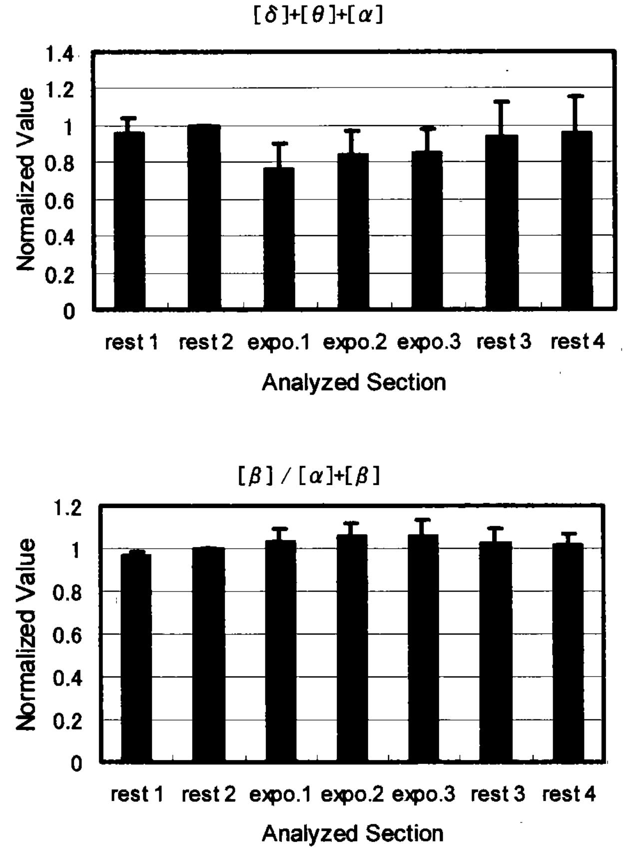

Fig.8 Variations of the fast wave ratios ([β] / [α]+[β]) and the amplitudes ([δ] + [θ] + [α]).

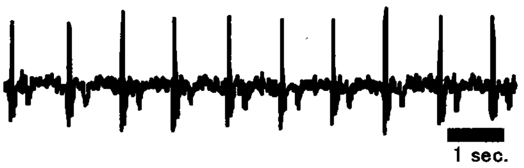

Fig.9 Measured ECG signals in field exposure.

increased with respect to the period "rest 2" ($p< 0.01$). In the experience with the therapeutic device, the effect often appears after the exposure rather than at the time of exposure. In addition, we have conducted the sham-exposure experiment following the same time course as this experiment. In the sham experiment, such a change was not observed. Considering these factors, the observed changes seemed to suggest the possibility that the field exposure influenced the sympathetic nervous activity of the subject.

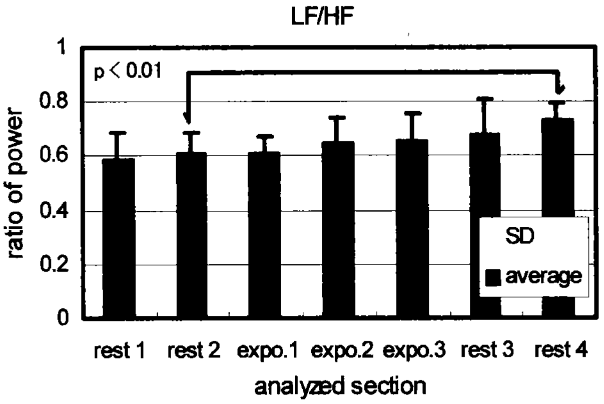

Fig.10 Temporal change of component ratio LF / HF of HRV spectrum. (N=9)

8. Conclusions

A telemetry technique was newly developed to measure the human EEG/ECG in a strong ELF electric field and at an alternating high potential. The EEGs / ECGs were measured satisfactorily from the subjects in the electric field of 300 kV/m and at the high potential of 30 kV. The measured EEGs / ECGs were analyzed respectively and the following results were obtained.

The changes were observed in the amplitude index of the EEG during electric field exposure. This suggested the possibility of the increase in the vigilance level of subjects.

Noticeable changes were observed in the spectral power of HRV, particularly in the parameter LF / HF which corresponded to sympathetic nervous activity. These changes suggested the possibility that the field exposure influenced sympathetic nervous activity of the subject. For the effect of the ELF electric field on the nervous system, further study is required.

The present work was supported in part by a grant from the Ministry of Education, Science and Culture of Japan.

(Manuscript received January 11, 2002, revised April 2, 2002)

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