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Influence evaluation of infrasound by using both of biological information and infrasound sensors in the vicinity of wind turbine facilities

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ABSTRACT

In recent years, wind power generation attracts attention. However, problem of low frequency sound generated by wind turbines and its influence on human beings have been gradually taken up in society. We investigated the influence of ultra-low frequency sound generated from wind turbines on human subjects/testers from both aspects of measurement of audible/infrasonic sound and multiple biometric information sensing systems. In the experiment outside, portable electroencephalographs and pulse wave sensors are used because only such small equipment can be used to perform biological information sensing outdoor, in the vicinity of a wind turbine facility. In order to calculate relax trends from the obtained biological information, a method based on previous analyses for obtaining relaxation degrees R is used. It is coming from the fact that content rate of each frequency band included in the electroencephalogram waveform varies depending on the human mental state in the brain wave. Also, in analyzing the heart beat wave, we used an analytical method to find stress degrees S by using the balance of autonomic nerve that can be calculated from the heart beat signal fluctuations. Here we would like to introduce the result using the above analyses methods for almost 30 examples.

1. INTRODUCTION

1.1 Background

Energy source conversion from the fossil fuel to renewable energy has recently been rapidly on going In particular, the wind power is recommended and widely introduced in countries around the world because relatively low power generation cost and high conversion efficiency etc. On the one hand, the wind power has feature that it makes generate infrasound of 20 Hz or less and sound of audible frequency during power generation (1). The noise level of sound generated by wind turbines is not noticeably high but, even within the relatively low noise level it is easy to occur the complaint from residents nearby, because many wind turbines have been built in a quiet rural area where weather conditions such as wind direction and speed are suitable in the mountain ridge. It has begun to be noticeable that noise problem of the sound by wind power generation since around 1998 in Japan. Then the problem was recognized and began to be researched about the influence of the wind power sound on human health in some of research institutes and in Ministry of the Environment. Among them, the sound power in low-frequency audible sound and infrasound range, lower frequency than 20 Hz and can’t be noticed by human ears, is less than the human hearing threshold curve for pure tone of ISO in its 1/3 octave band sound pressure level distribution as well as the limit curve for evaluation of low frequency sound proposed by Moorhouse et al. (2011), it turns out that difficult to recognize the component of low-frequency audible sound and infrasound region of wind turbine noise. For that reason, it can’t be denied the possibility of low frequency sound to harm the human health of residents nearby. It is mentioned that the same kind of health effects arise in the paper of Jeffery et al. (2014). Because it is a possibility adversely to affect human life physically, mentally, and socially, with causing annoyance when it is extremely close to wind farm (1, 2). Main health damage according to low frequency sound are mentioned the dizziness, sleeplessness, stiff neck, nausea, etc. It is also the

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feature that there are many indefinite complaint and individual differences are large. Also, according to Pierpont (2009), among the wind power generation sound, she suggests not only sounds in the audible range that the eardrum and middle ear can detect but also sound below the audible sound (infrasound) to occur symptoms by body's balance sense abnormality according to resonance of bone conduction sound and each part of human body, and she named those symptoms with Wind Turbine Syndrome (WTS). The influence on the brain by balance sense abnormality is mentioned the involuntary reflection and vestibular reaction of muscle, vigilance state (awakening), spatial processing and spatial memory, physiological response of fear, disgust learning. In the same book, it has reported that it caused sleeping disorder, headache, ear fullness by noise of 10 Hz or less in one of symptom examples in Germany (3, 4).

Pierpont (2009) has mentioned that body's valance sense system is something as shown in Table 1 and it arises contradiction, if at least two systems in systems of 1-3 does not function properly (3, 4). Also, it is current status that symptoms by lower audible component of wind turbine power generation sound is that individual differences are large like WTS and there are still many unclear points scientifically. But, one or more in the systems of Table 1 are hindered by lower audible component of wind turbine power generation sound and contradiction with other systems arises, so it has been thought that symptoms may arise the cause of the body's balance sense abnormality.

Table 1 – Type of valance sense system of body's (3, 4)

①	Eye (Vision system)
②	Upsetting of the inner ear, Position sense organ (Vestibular system)
③	Body muscles, Extension receptor of joint and sense of touch receptor of skin (Somatic sense system)
④	Extension of organ of belly and breast, Baroreceptor

In our laboratory, a biological information sensing experiment near a wind farm was carried out by Yoshinaga (2018). The content is to view the stress tendency of the human affected by the wind power generation sound by measuring the personal biological information data when exposed wind power sound for a short time, and compare the obtained data with simultaneously measured infrasound data. For the outdoor experiment he developed low-cost and portable biological information sensing system with a pulse wave sensor (PWS) and an electroencephalograph (EEG) (5). He confirmed evaluation of the sensing system and the infrasound signal of a few Hz observed at a site 500 m from the wind turbines during outdoor experiment and small stress tendency but with only 5 samples.

1.2 Purpose

In this research, the purpose is to try the evaluation of the influence of infrasound components on humans in the vicinity of wind farm by collecting the outdoor experimental samples for nearly 30 cases that can used for statistical analysis.

2. EXPERIMENTAL EQUIPMENT

2.1 Biological Information Sensing

In order to perform biological information sensing in the outdoors, we must put emphasis on portability and relatively low cost characteristics, thus we used the same combination of EEG and PWS as was used in previous studies. Human stress tendency can be calculated by using the obtained electroencephalogram data measured by an EEG. The EEG used in this paper is the MindWave Mobile and MindWave Plus manufactured by NeuroSky Co. MindWave Mobile Plus is an upgraded version of the MindWave Mobile but the shape and design are the same. Pairing the EEG and a PC is via Bluetooth wireless connection, with a sampling rate of 512 Hz.

In this research, we measured the heart beat that has high correlation with human stress condition. We can calculate human stress indicators by analyzing the obtained data of PWS. Here, reflective pulse wave measurement method of photoplethysmography was used. This measurement method can capture a waveform of the volume change in blood vessels that occurs as the heart pumps blood. The PWS used is manufactured by Rasbee Co. which is inexpensive and also has portability. In the experiment, we attached this small PWS to the experimental subject's fingertip with black magic tape carefully so as not to let the light come in. As for specifications of PWS, LED wavelength of 609 mm and drive voltage of 3-5 V are applied. Volume change of blood vessels observed by PWS appears as waveform called finger plethysmogram but the pulse wave sensor used in this study has mechanism to output a waveform called acceleration pulse wave as a signal. This is a waveform obtained by the finger plethysmogram after passing through a second order differential circuit in each PWS as shown in the Figure 1. To calculate the degree of stress S from pulse wave measurement, it is important to see and analyze a peak of each wave pulse. But, there are some difficult cases in finding the peak of each wave pulse with using the finger plethysmogram. Therefore, acceleration pulse wave, differentiated twice from the measured pulse wave, is used in many cases in consideration of precise peak time analysis.

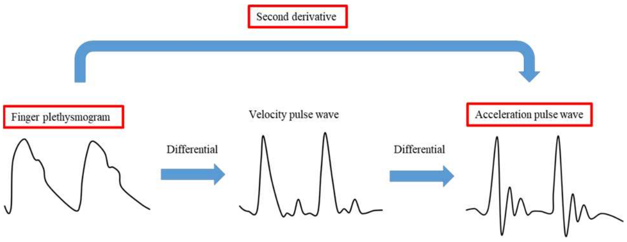
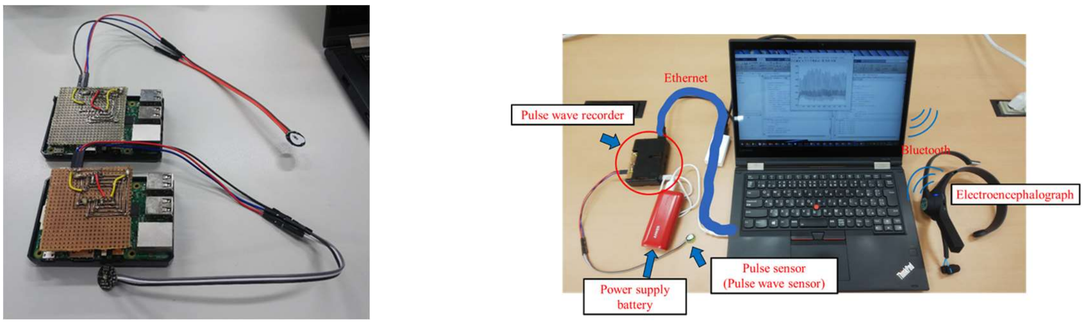


Figure 1 – Relationship of finger plethysmography and acceleration pulse wave

2.2 Existing System

In our previous research, we developed a recorder system to collect pulse wave data measured by a PWS. A Raspberry Pi2 Model B and an A/D converter MCP3208 of Microchip company were used. A reason of using the Raspberry Pi2 Model B is its high affinity with MATLAB software development language. Though, there was only one device developed in the prior research but, as for the current research designed with using three devices at the same time, we made two more devices (figure 2a) by using the same schematics.

The recorder developed in prior research as well as summary diagram of the entire system is shown in Figure 2b. As an overview of the system is to measure pulse wave signal with the PWS and to convert it to digital data that can be handled by logging program on a PC through an A/D converter via Ethernet cable connecting between Raspberry Pi and PC. Also, it was saved as a text file by the program and the pulse waveform can be displayed and reviewed in real time. The EEG has a Bluetooth connection with the PC, and the data logging time is displayed on a program window with storing, brain wave data (5). At the present stage, as the Raspberry Pi is used only as a handling medium to send the pulse wave data to the PC, it could be more smart in outdoor operation if we develop a program to use the Raspberry Pi as a recording device.



(a) Pulse wave recording device (Two sensors) (b) System outline

Figure 2 – Developed biological information sensing system

2.3 Infrasound Observation Sensor

Infrasound observation sensors we used are ParoScientific Quartz crystal vibration barometer Model 6000-16B (NanoBarometer). We have been operating the sensors for disaster mitigation in usual. Here we adopted it because it can observe infrasound component of sound waves generated from wind turbines. Also, we used two sets of dedicated data logger system, NanoLogger (Mitomi Giken NL-6000C) released from Toho Mercantile Co. in combination with the NanoBarometer.

2.4 Experimental Design

In the experiment, we organized an experiment at a place of 500 m distance from a pair of wind turbines as well as at another place without any wind turbines. As an outline, we used an eye mask and a pair of earphones per each subject person to wear with sitting on a chair, attaching an EEG and a PWS with rest condition. Here we measured brain and pulse waves with their eyes closed for preventing influence of myoelectric potential changes by their eye blinks. Simultaneous measurements were carried out for 1 to 3 people each, with consideration of personal area with a separation of 3.5 m or more. The experiment task is as shown in table 2. White noise was exposed from the earphones for a purpose of initial state control for the difference by place and time for each subject. After the measurement, we added a psychological questionnaire written in consideration of subjective data. Also, we consider counterbalance in total, having experiments with swapping the order of experimental place for each day. This is to prevent bias of stress by order of experimental place. Weather information in measurement place at the time of experiment is noted as shown in table 3.

Table 2 – Environmental information in measurement place

Experiment order	Task
1	White noise exposure for 5 minutes
2	Environmental sound (No sound from headphone) for 5 minutes, 1st time
3	Environmental sound (No sound from headphone) for 5 minutes, 2nd time
4	Psychological questionnaire

Table 3 – Experiment task

(1) Place with wind turbine				(2) Place without wind turbine				Other
Experiment day	Weather	Temperature (℃)	Wind speed (m/s)	Experiment day	Weather	Temperature (℃)	Wind speed (m/s)	Order
12th November	Cloudy/Rain	10～11	0～1.0	12th November	Cloudy	18.2～21	0～0.5	(2) -> (1)
14th November	Sunny	12～26	1.0～4.0	14th November	Sunny	14～22	1.5～5.0	(1) -> (2)
16th November	Cloudy/Sunny	12～18	0.5～1.5	16th November	Sunny	17～33	0～0.9	(2) -> (1)
20th November	Sunny	13～26	2.0～4.6	20th November	Sunny	21～27	0～2.0	(2) -> (1)
21th November	Cloudy/Sunny	10～20	1.0～3.6	21th November	Cloudy	17.8～20	0～0.5	(2) -> (1)
30th November	Sunny	14～20	0.5～3.0	30th November	Sunny	22～29	0～1.5	(2) -> (1)
5th December	Sunny	18～26	1.5～4.0	5th December	Sunny	16.5～25	0～2.0	(1) -> (2)
7th December	Cloudy	10～11	1.0～3.0	7th December	Cloudy	9～14	0.5～3.0	(1) -> (2)
12th December	Cloudy	7.5～13	3.0～6.5	12th December	Sunny	15～19	1.5～3.0	(2) -> (1)
14th December	Sunny/Cloudy	4.5～10	0.5～6.0	14th December	Sunny	10～17	1.0～3.6	(1) -> (2)

3. ANALYSIS METHOD

3.1 EEG Analysis

In this research, we referred an analytical method used in a previous study (6) on relaxation effect by relaxation sound exposure by using only a simple EEG because we also used a one EEG. In the analysis method, we use a ratio of two individual frequency bands included in the electroencephalogram waveform changes by mental state of people. It is known that θ wave (5-7 Hz) and α wave (8-12 Hz) are prone to increase proportionally in the relaxed state, while β wave (13-19 Hz) is prone to increase proportionally in the stressed state. Based on such tendency, we can investigate the human stress level with numerical values by doing EEG analysis (6). We derive an index R as the degree of human relaxation with a frequency content rate of θ wave, α wave, and β wave as is shown in the following equations.

$$P_i = \sum_{f=F_{\min}^i}^{f=F_{\max}^i} V_f \,/ \left(F_{\max}^i - F_{\min}^i + 1\right) \quad (1)$$

$$P_{sum} = P_\theta + P_\alpha + P_\beta \quad (2)$$

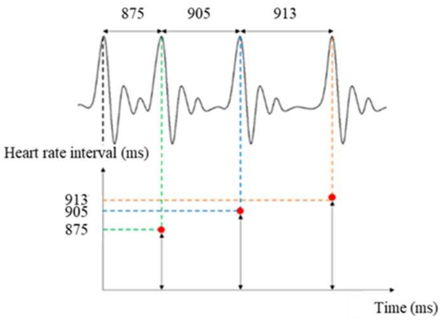
$$G_i = P_i / P_{sum} \quad (3)$$

$$R = \left(k_\theta G_\theta + k_\alpha G_\alpha\right) / \left(k_\theta G_\theta + k_\alpha G_\alpha + k_\beta G_\beta\right) \quad (4)$$

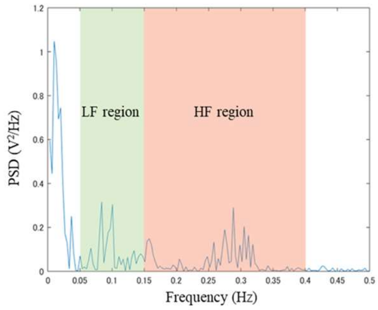
The index R is obtained by dividing the sum of power content rate that is often appeared in the relaxed state by the overall power content rate. The larger the value of R, the higher the degree of relaxation, thus high value of R means that the subject does not feel much stress. By this relation, we can roughly see the stress tendency for each person.

3.2 Pulse Wave Analysis

In pulse wave analysis, we used analytical method of Heart Rate Variability (HRV) in order to obtain the degree of stress using autonomic balance information that can be calculated from fluctuation of heart beat signal (7). The analysis method can also be adapted to pulse wave period that can be calculated from the heart beat activity cycle. In the HRV, we can see heart rate fluctuations by plotting the difference of the second derivative peak time on the vertical axis with respect to the peak interval of the pulse wave waveform (heart rate interval) and to create an RRI graph (figure 3a). We can get a degree of relaxation R from LF/HF ratio by using power spectrum analysis (figure 3b) on the heart rate fluctuation, with integrating the appeared low frequency component (LF:0.05~0.15 Hz) and high frequency one (HF:0.15~0.40 Hz), respectively.



(a) RRI graph



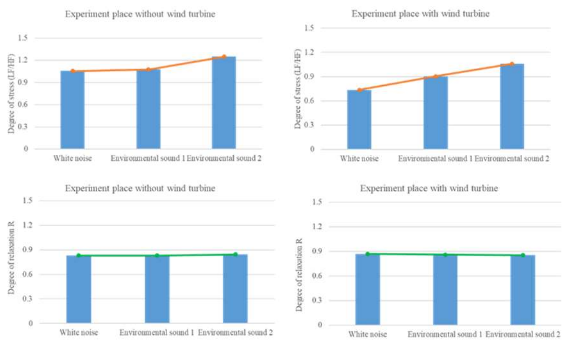
(b) Power spectral density (LF, HF range)

Figure 3 – Graph in pulse wave analysis

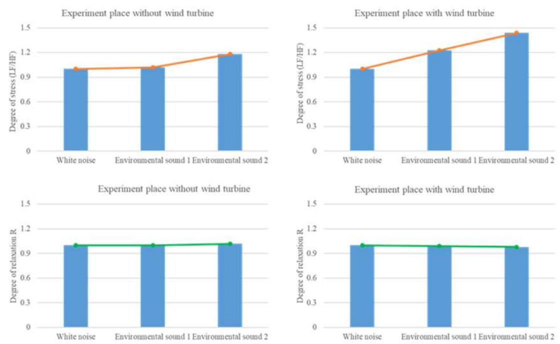
4. RESULTS

4.1 Stress Tendency

We successfully collected a data set of about 30 cases by changing the experimental design. Here, we show in the figure 4a the median value of the data collected for 29 persons. The top indicates pulse wave data and the bottom is EEG data. The individual graphs in each panel are arranged in experiment task order, i.e., from the left, the white noise (sound from earphones), environmental sound for the 1st time (no sound from earphones), and that for the 2nd time. We show the result at the experimental place without any wind turbines on that with wind turbines on the right. Also, we show in figure 4b that another version normalized with the white noise as 1.



(a) Comparison of stress between PWS and EEG in outdoor experiment (Median data)



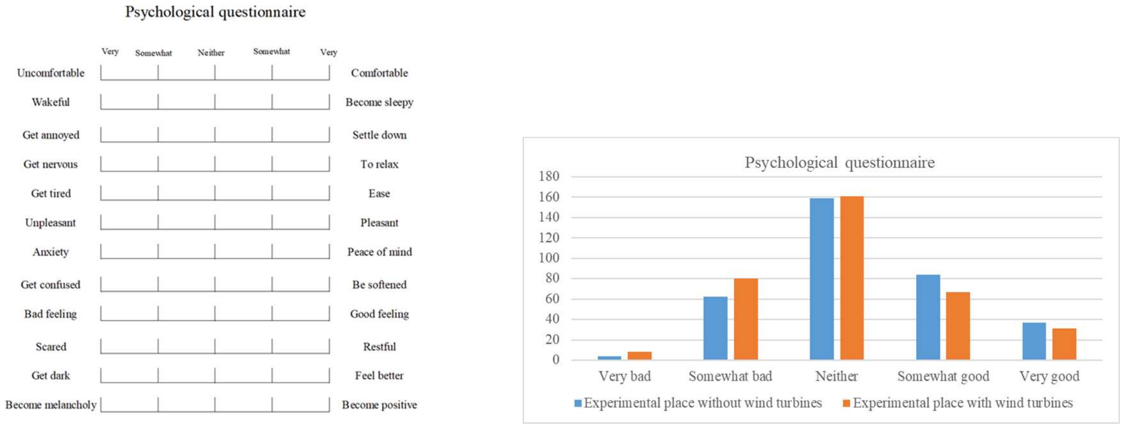
(b) The same as normalized with white noise as 1

Figure 4 – Stress tendency result

Looking at the results in figure 4a, the data obtained at the experimental place with wind turbines show slightly higher degree of stress of pulse wave than at the experimental place without any wind turbines, while in the EEG, we found that there is no apparent change in the degree of relaxation between the both experimental places. The normalized result in figure 4b also shows the same tendency.

4.2 Questionnaire

The outline of the psychology questionnaire we used in each experimental place after the experiment as well as the result are shown in figure 5.



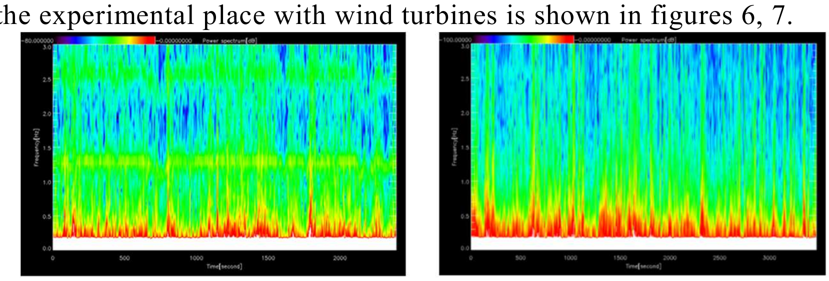
(a) Psychological questionnaire (b) Psychological questionnaire result

Figure 5 – Psychological questionnaire summary

Looking at the psychological questionnaire results shown in figure 5b, with using the questionnaire of figure 5a, we found that the percentages of person choosing very bad or somewhat bad in the experimental place with wind turbines, as well as those of very good or somewhat good in the experimental place without wind turbines were large.

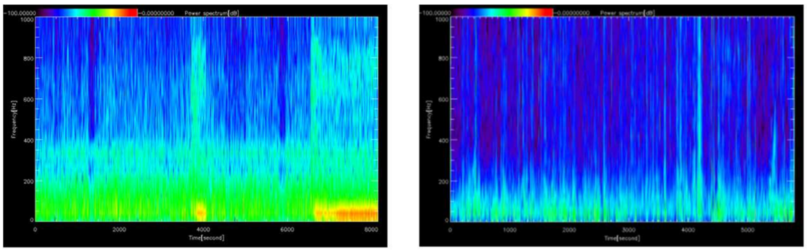
4.3 Power Spectrogram

We analyzed infrasound data observed by using the NanoBarometer with WAVE SPECTROGRAM software developed in our laboratory (Sorimachi, 2017) (8). We also analyzed the audible around data by using an IC recorder at the same time of the experiment. In the comparison of the both data of the infrasound sensor and the IC recorder obtained at the experimental place with wind turbines (500 m from the wind turbines) and at the experimental place without wind turbines in the most intense wind day and in the weakest wind day, we could confirm the peak at around 0.2-0.5 Hz in the intense wind day in the infrasound spectrum. Also, in the experimental place with wind turbines, we could confirm the peak at around 0.2-0.3 Hz in the weaker wind day. However, in the windy day and quiet day comparison with the IC recorder only, there found no large difference between the data of experimental place with wind turbines and those of experimental place without wind turbines. Additionally, the result of comparing the power spectrogram of infrasound data and IC recorder data measured directly beneath the wind turbines in the same period in the most intense wind day at the experimental place with wind turbines is shown in figures 6, 7.



Directly beneath the wind turbines (about 30 m) Experimental place with wind turbines (500 m from the wind turbines)

Figure 6 – Comparison of power spectrograms of infrasound range by distance from the wind turbines



Directly beneath the wind turbines (about 30 m) Experimental place with wind turbines (500 m from the wind turbines)

Figure 7 – Comparison of power spectrograms of audible sound by distance from the wind turbines

Looking at Figure 6, in the directly beneath the wind turbines (about 30 m distance) and experimental place with wind turbines (500 m from the wind turbines), we were able to confirm a peak band of infrasound at the same frequency range (0.2-0.5 Hz). Also, in the directly beneath the wind turbines (about 30 m), we could confirm its harmonics. Looking at Figure 7, in the IC recorder of directly beneath the wind turbines (about 30 m), there is a peak likely a motor sound of the wind turbines at about 350 Hz, while the peak can't be seen at the experimental place of 500m.

5. IMPACT ASSESSMENT AND DISCUSSION

In this research, we successfully collected biological information data for 29 persons under the both conditions of near of and without the wind turbines. However, the stress tendency of each experiment cooperator showed a lot of variation, even in the cases of parallel simultaneous measurement in the same environment. So, we tried to see overall tendency by taking the average of the whole data, however in the experimental place without wind turbines, it can be confirmed that it makes larger error range against the environmental sound for the 1st time in the experiment task in the stress level obtained by pulse wave, namely we found the variability of the data was large. The white noise exposure was used for the purpose of normalizing the stress status, we leveled with the white noise experiment as is shown in figure 4b. By this, it became possible to compare the stress tendency depends on experimental places. At this moment, we don't know any specified distributions that can clearly support whether all the collected sample data are statistically meaningful. But, if we can say that once some probability distribution functions are applied as indicators of human biological information, the dataset might be statistically meaningful.

In this kind of experimental data analysis, not only influence by the wind turbines, but also we should consider that it will have many types of influence by the other external factors, so we should try to see the stress tendency by changing normal environmental conditions such as temperature and wind speed. Nevertheless, in the outdoor pulse wave sensing, we could see some tendency as a result shown in figure 4b. While, it was difficult to see any clear trends in the EEG data, and there were several cases in which the EEG showed stress tendencies opposite to the PWS result. Precise measurement would be difficult because the EEG used is a simple EEG with only one sensing point. For that reason, emphasis on securing sample numbers and improving more appropriate experimental design and analytical methods is necessary. In the pulse wave analysis, we think that some unclear waveform to be measured makes a problem in automatic peak detection failure because there are many individual characteristics in pulse wave signal and unusual cases can be obtained with unstable peak in each heartbeat. For this reason, we think that we have to increase the knowledge of biological information sensors and its performance. Improving experimental efficiency for automate analysis method is also important. If the analysis time were shortened, we could handle a lot of data and could discuss data reliability. In this experimental design, we performed parallel simultaneous measurement to conduct the measurement efficiently. But, there were many troubles that the connection was interrupted during the measurement by the condition of Bluetooth connection of the EEGs, there was a case that the measurement time is longer than that of in the case of one person.

As for the infrasound measurement, we know that the rotation period of the wind turbine is about 2 to 3 seconds from video movies taken directly beneath the wind farm. As it uses 3 blades, we can see the repetition period that one blade passes through one point on the circumference is about 1 second. Whereas, it is conceivable that the frequencies generated by turning of the windmill are around 0.45 Hz and 1.35 Hz that is actually shown in the figure 6. Moreover, we can confirm peaks and their harmonics in the same infrasonic frequency ranges. Therefore, this wave is considered as artificial wind pressure vibration. Also, in the place directly beneath the wind farm (about 30 m) and experimental place with wind turbines (500 m from the wind turbines), because the peak can be confirmed around the same frequency band, we can understand the infrasonic wave of 1.35 Hz can propagate but with significant attenuation for the place 500 m away from the wind turbines. Further, in the IC recorder spectrum directly beneath the wind farm (figure 7) showed a peak likely of the motor sound at around 350 Hz, this peak can't be seen at 500 m away. Moreover, we found that in the 500 m point, it is affected only by the infrasound component of wind power generation.

Also, in the psychological questionnaire, we found that the experimental place with the wind turbines shows higher stress tendency. In the counter balance, the experiment cooperator who experienced the experiment in the order from the experimental place without wind turbines to that with the wind turbines were 14 persons, while there were 15 persons who experienced it in reverse order, so it is almost leveled. We can consider that some other factors are working, because stress tendency is higher at the experimental place with wind turbines. However, it may not be directly connected to wind turbines. For example, the road situation up to reach the both points, it may be also necessary to consider the situation that there are more mountainous roads in the experimental place with wind turbines. It should be in emphasis that for the both of objective sensing experiment results as well as subjective psychological questionnaire ones, the tendency of increasing the stress in the experimental place with wind turbines were found.

6. CONCLUSION

In this research, as a purpose to try evaluating the influence of infrasound components on human health in the vicinity of wind farm, we conducted parallel simultaneous measurement of pulse wave and brain wave by using small biological sensing devices, securing the number of experimental samples. We improved efficiency of the outdoor experiment, collecting 29 samples of data. Finally, we found a tendency that it seems rather easier to feel stress near the wind farm than the usual place without wind turbines, though the tendency was slight.

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