Physiological Responses Induced by Pneumatic Noise

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ABSTRACT

Electroencephalograms EEG and topographies of experimental subjects heard pneumatic noise have been measured. Auditory evoked potential AEP and event-related potential ERP occur one after another. Alpha waves disappear and beta waves appear as the result of analysis of frequency map. Loudness of pneumatic noise is estimated by Steavns power law used brain potential of beta wave in ERP.

In addition, physiological responses, namely, heart rate, respiration, and sweating have been measured. Influence on them through the autonomic nervous system is demonstrated. Explanation based on function of the brain is given. Subjects fall into two categories, using a personality test. Even subjects who are hard to feel the stress are influenced by the pneumatic noise. These results indicate that the pneumatic noise is stressor.

KEY WORDS

Silencer, Steavns power law, Electroencephalogram, Heart rate, Autonomic nervous system

Introduction

Pneumatic system having superior characteristics is suitable for assistance to men. Although the pneumatic system has been developed to cooperate with men, there are some problems. Particularly, noise generated from components in the system jars on us. The noise is generally evaluated by A-weighted sound pressure level in order to estimate easily the loudness level. In Japanese Industrial Standard, a method of measuring the level is provided [1]. However, we feel that the noise decreased that level is harsh. Therefore, the discordant noise must be study from psychological and physiological views in addition to physical view.

This paper is intended to report physiological responses induced by pneumatic noise. The responses are investigated experimentally from the two points of view, one electroencephalogram EEG and frequency map and the other autonomic functions.

Basic equation

Relation between sensual quantity and physical quantity is expressed by Stevens power law [2]. This is given by Equation (1).
\[
\log_{10} I = n \cdot \log_{10} (S - S_0) + k
\]  \(1\)

Here \(I\) denotes the magnitude of sense and \(S\) denotes the strength of stimulus. \(S_0\) is the reference sound pressure 20 \(\mu Pa\). \(k\) is constant and \(n\) is an exponent that varies according to kinds of stimulus.

**Experimental**

Figure 1 shows a pneumatic circuit and system 1 to measure the electroencephalogram EEG. The system 1 consists of disk electrodes, an electrode box, an electroencephalograph, and a computer. The disk electrodes put on scalp of an experimental subject using the ten-twenty electrode system as shown in Fig.2. Referential derivation is used and reference electrodes are fixed on earlobes. Space between the disk electrodes and the scalp is filled with paste so that the contact resistance is below 10k \(\Omega\). Both EEG topography and frequency map are calculated from the EEG by the computer. Pneumatic noise is the reduced jet noise that is generated continuously from the compressed air flow through a restriction and that is made small by a pneumatic silencer. The intensity is adjusted by the ratio of downstream pressure \(PL\) to upstream pressure \(PH\) at the restriction.

The level of back grand noise B.G.N. in the anechoic room, which is defined as A-weighted sound pressure level without flow, is below 40dB(A). Both temperature and humidity in the anechoic room are adjusted.

In the anechoic room an experimental subject hears the pneumatic noise with his eyes closed and awake for thirty seconds after his conditions keep stable physiologically. Healthy experimental subjects have normal hearing ability. In this experiment, four experimental subjects are examined. An experimental subject sits in a deck chair toward the pneumatic silencer. The center of subject's head is located at the position of 1 m and \(\theta=45^\circ\) from the pneumatic silencer. At this position A-weighted sound pressure level of the reduced jet noise is 74dB(A).

Figure 3 shows system 2 to measure heart rate, respiration, and perspiration. Electrocardiogram ECG is measured by an electroencephalograph used as an electrocardiograph in the system 2. Heart is observed from left subject's side using unipolar chest leader. For measurement of subject's respiratory rate, the pressure...
caused by breath through a nose is led to a digital manometer. A subject breaks a sweat so that resistance between two electrodes on a thumb is varied and it is converted to voltage by a perspiration meter. It is confirmed that the voltage is proportional to the amount of sweat. Data of heart rate, respiration, and perspiration are sent to a digital oscilloscope and are analyzed by the computer. In this experiment, four experimental subjects are examined.

Furthermore, a personality test is performed using a questionnaire method [3]. In the test, there are questions about behavior, habits, and so on.

Results and Discussion

EEG, EEG topography, and frequency map

Figure 4 shows the EEG for one minute when an experimental subject hears the reduced jet noise. There is no stimulus of noise in the first half of one minute i.e. from 0 second to 30 seconds (the first stage), while the reduced jet noise stimulates an experimental subject in the second half of one minute i.e. from 30 seconds to 60 seconds (the second stage). In the first stage, amplitude of the EEG measured from sixteen disk electrodes is small. Artifacts for example movement of eyeballs aren’t contained. In the second stage, various activities appear and the EEG is divided into three periods:

- In the period I, spikes occur for 1.6 seconds.
- In the period II, high frequency waves continue for 11.6 seconds.
- In the period III, amplitude of waves decreases.

Figure 5 shows EEG topographies calculated. Brain potential increases at the auditory area in the period I and this is the auditory evoked potential AEP. The AEP is one of the stimulus-related potentials. In the period II, the brain potential in the frontal association areas increases widely and this is the event-related potential ERP. The ERP is related to function of high perception for example understanding the stimulus. In the period III, the brain potential in the widespread area decreases and this is the accommodation.

Brain potential is generally classified into four frequency components: delta wave, theta wave, alpha wave, and beta wave. Particularly, the alpha wave and the beta wave are considered. The delta wave and the theta wave are excluded because they occur mainly while sleeping. The alpha wave and the beta wave are divided into both the low frequency component, which is denotes by subscript 1, and the high frequency component, which is shown by subscript 2.

![Figure 5 EEG topographies](image-url)

![Figure 6 Frequency maps](image-url)
Table 1 displays frequency ranges of the alpha waves and the beta waves.

<table>
<thead>
<tr>
<th>Alpha wave (Hz)</th>
<th>Beta wave (Hz)</th>
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<tbody>
<tr>
<td>$8 \leq \alpha_1 &lt; 10$</td>
<td>$13 \leq \beta_1 &lt; 20$</td>
</tr>
<tr>
<td>$10 \leq \alpha_2 &lt; 13$</td>
<td>$20 \leq \beta_2 &lt; 30$</td>
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Figure 6 shows frequency maps. At the first stage the alpha waves occur at the occipital region of head. It is shown that the subject is relaxing. In the period II, the beta wave appear at the frontal and the central region of head and the alpha waves disappear owing to the mental activities. In the period III, alpha waves appear again.

**Evaluation of noise considering sensitivity**

The loudness of the reduced jet noise is evaluated using Stevens power function. Firstly, the period contained the feeling of loudness against the noise is determined. The AEP doesn't depend upon the mental conditions and the latency of the AEP is 300 ms [4]. The latency of the ERP is larger than that of the AEP because information in the sensorial area is transmitted to the area where the ERP occurs [5]. The electromyogram EMG is included in the period I because the subject is surprised to hear the sudden noise and part of the body is moved reflexively. The experimental subject doesn't feel the strain in the period III. These results means that the loudness against the noise is reflected on the period II except for two periods.

Secondly, it is reported that men judge unpleasant in the limbic system and that feeling causes the beta wave [6]. Therefore, the brain potential of beta I is substituted for the magnitude of sense I in Eq.(1)

Thirdly, the brain potential of beta I is the average of four disk electrodes F3, F4, C3, C4 for 10 seconds in the period of II. Four disk electrodes are located on the frontal and the central region of head. These regions manage high mental activities for example emotions, thoughts, and sentiments.

Figure 7 shows the relation between the brain potential of beta I and sound pressure of the reduced jet noise. A value of $n$ in Eq.(1) determined by Fig.7 is 0.15.

**Effect on Autonomic functions**

Figure 8 represents electrocardiogram ECG, pneumogram, and sweating at rest. P wave, Q wave, R wave, S wave, and T wave are appeared regularly in the ECG. The R wave occurs at late diastole of ventricle and the heart rate calculated from an interval of the R waves is 65.3 beats per minute. Respiratory rate obtained from the pneumogram is 12.9 times per minute. Perspiration at rest is controlled automatically by respiratory center. Standard values of both the heart rate and the respiratory rate at rest [7] are shown in Table2. The measured values are within the ranges of standard values. What the voltage between two electrodes for the measurement of sweating keeps constant as shown in Fig.8 is to occur the insensible perspiration for thermoregulation.

<table>
<thead>
<tr>
<th>Heart rate</th>
<th>Respiratory rate</th>
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<tbody>
<tr>
<td>60 ~ 90</td>
<td>12 ~ 20 times per minute</td>
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Figure 8 ECG, pneumogram, and sweating at rest
Figure 9 shows the heart rate for one minute. One minute is divided into the same stages as before. The heart rate at the first half of one minute (the first stage i.e. from 0sec. to 30sec.) fluctuates because of the respiratory sinus arrhythmia based on the activity of the parasympathetic nervous system. The frequency of the fluctuation is 0.23Hz. An average of the heart rate in the first stage is 62.0 bpm. The heart rate fluctuates after it increases rapidly at the beginning of the second half of one minute (the second stage i.e. from 30sec. to 60sec.) because of the antagonism caused by the sympathetic nervous system and the parasympathetic nervous system.

Figure 10 shows the mean of coefficient of R-R interval variation CVR_R of four experimental subjects. The CVR_R is defined as division a standard deviation of the R-R interval by the mean of the R-R interval. The R-R interval is the time between two R waves in ECG. The CVR_R of the reduced jet noise in the second stage increases, comparing with that of no stimulus in the first stage.

The respiration rate of the reduced jet noise for one minute is shown in Fig.11. The respiration rate in the second stage increases. This is respiration caused by a special reflex.

In Figure 12, the electric potential in the second stage increases because of mental sweating.

These results of autonomic functions and those of brain potential are considered, bringing them closer to each other. Pneumatic noise is transmitted to hypothalamus, limbic system, and cerebral cortex through auditory organs as shown in Fig.13. The information of emotion judged to be unpleasant in the limbic system is projected on the cerebral cortex. This results in both occurrence of the beta wave and the alpha attenuation. Furthermore, the information is transmitted to the heart and the lung from the hypothalamus through sympathetic nerve system so that the heart and the lung are activated. The heart rate fluctuates and the mental sweating is generated by the information from the cerebral cortex. Those responses are a result of defense reaction to a stressor.
Four experimental subjects are classified into two personalities: type A and type B. Persons of type A feel a lot of strain against the external stimulus, on the other hand, persons of type B feel a little strain. Three subjects that belong to type B indicate the physiological responses as well as a subject of type A.

Figure 13  Schematic diagram of autonomic functions controlled by brain

Conclusion

The physiological responses induced by pneumatic noise have been investigated experimentally. It has been shown that loudness of noise is evaluated from Stevens power law based on the beta wave of the event-related potential. The loudness of the noises generated from pneumatic equipments will be able to compare using the value of n.

Furthermore, it has been made clear that the pneumatic noise influences the heart rate, the respiration and the mental sweating and that the pneumatics noise is stress.

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