EEG REACTION UNDER LOW FREQUENCY NOISE EXPOSURE

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EEG reactions under different low frequency noise exposures are introduced in this paper, which include the comparison of low frequency noise and pink noise, low frequency noise combined with different bandwidths pink noise and low frequency noise with additional visual stimuli. The power spectral density (PSD) variation of Alpha and Beta band at the temporal lobe and frontal lobe of the cerebral cortex were found significant relationship with the subjective annoyance evaluation result. Noise sensitivity was found as an important factor in most of the observations. It was demonstrated that EEG was effective for objective evaluation as a physiological index and could be an explanation for low frequency noise sufferers.

1. Introduction

Low frequency noise (LFN) is a common source of annoyance at home and in the work environment. It can involve an exceptional annoyance or stress for the sufferers, even with just exceeded level above hearing threshold [1]. The exact reason why some people have serious problems with LFN is unknown, and a lot of studies related with LFN were done with questionnaire surveys, listening tests, psychological experiments as the dominant methods [2]. The subjective annoyance caused by noise was found related to people's cognition, experiences and emotional states [3]. Due to the limitation of psychological experiments, the investigations of physiological effects of noise on auditory systems and the neuroendocrine system have been studied to explore the relationship between subjective annoyance and physiological parameters. Earlier research results of human brain physiology showed that brain activities could occur with external stimulation simultaneously [4]. The concept was proven that people generate stress response and their dynamic EEG may change when they exposed to noise. The sum of the relative power spectrum density of Theta and Alpha waves were found increased with the subjective annoyance increasing [5].

The purpose of this paper is to summarize the primary observation of EEG reactions under different LFN exposure situations. The aim was to find out the correlation between the PSD changes of EEG bands and the subjective assessment result, particularly in which function area of the brain and which EEG band. Additionally, the discussions about the effect of different psychological questionnaires on the perception of LFN and the EEG changes were also collected. Another aim was to demonstrate that the EEG can be an effective tool to use as a physiological index for the objective evaluation related with LFN, and can be used for the further study for LFN sufferers.

2. The experiments

All the tests were taken in the same chamber with low background noise level (17 dBA) and the LFNs were presented with the same loudspeakers (Type Neumann KH 120 + KH 870). The EEG equipment was different but the analysis software to calculate the PSD of 10 EEG bands was the same - Neuron Spectrum. The detail for the frequency ranges of the EEG bands is in Table 1.

Table 1. The frequency ranges of EEG bands [6][7]

	Frequency range		Frequency range		Frequency range
Theta (θ)	4 – 8 Hz	Alpha (α)	8 – 13 Hz	Beta (β)	13 – 30 Hz
Theta1 (θ1)	3.5 – 5.4 Hz	Alpha1 (α1)	7.4 – 9.9 Hz	Beta1 (β1)	12.5 – 17.9 Hz
Theta2 (θ2)	5.4 – 7.4 Hz	Alpha2 (α2)	9.9 – 12.4 Hz	Beta2 (β2)	18 – 23.9 Hz
				Beta3 (β3)	24 – 30 Hz

2.1 The different perception of LFN and PN

Firstly, a primary EEG test was made to observe whether there were different perceptions between LFN and other noise. Pink noise (PN) was proven that it had significant effect on reducing brain wave complexity [8], therefore, PN with frequency range from 20 Hz to 20000 Hz was chosen as the reference noise to compare with LFN. LFN was the Brown noise through Butterworth low pass filter with the cut-off frequency at 125Hz and the order 10. Both noises were set to 50 dBA. Due to the limitation of the EEG equipment (BIOPAC MP150), only one electrode position T4 was used in the test. Three subjects with normal hearing ability were participated. The subjects answered questionnaires included "Noise Sensitivity (NS)" [9], "General Health Question – 28 (GHQ-28)" [10] and "Positive and Negative Affect Schedule (PANAS)" [11], and results showed that they have similar GHQ-28 and PANAS score but different NS levels. Subject 1 and 3 had normal noise sensitivity and Subject 2 was very sensitivity to the noise. The EEG recording was made synchronously when the subjects were exposing under LFN and PN each for 5 min, and there were same length duration pause in silence before and between two noises. After the test they gave their subjective annoyance evaluation for two noises. The PSD were calculated and compared with the subjective annoyance result for each one. The results showed that the PSD of Beta and Beta 2 bands had a negative correlation with the annoyance judgment result, which meant the less annoyance the subject felt, the larger the Beta band energy was. The PSD changes along time were also analysed, and it was found that the subjective annoyance level might have a relationship with the first peak of Beta band. The PSD trends of Beta band for PN were similar among the three subjects, but quite different for LFN between Subject 2 and the other two regarding that the first peak of Beta band appeared with Subject 2 later than with the other ones. This could due to the different noise sensitivity levels.

The negative correlation result between PSD of Beta band at Temporal lobe and the subjective annoyance evaluation was agreed with the previous conclusions that Beta band activity especially over Temporal lobe reflected emotional phenomena [12] and more Beta activity was presented in the Temporal lobe during positive than during negative emotional tasks [13].

2.2 LFN combined with different bandwidth PN

The second test was arranged to prove the feasibility of the indirect method to reduce the subjective annoying feelings caused by LFN [14, 15], and at the same time EEG was used to observe the brain reaction during the test. The test signals were two LFNs combined with different bandwidth PNs (Table 2). LFN1 was recorded from a heat pump unit in the centre of an office [14] and LFN2 was obtained by the same procedure as the LFN in the last test but with 160 Hz cut-off frequency. The SPL of both LFNs was 45dBA and the additional bandwidth PN was set to 20 dB. The duration of each signal was 2 min with 1 min pause in silence between two signals. Brain wave was recorded with the Emotiv EEG neuroheadset, which had 14 fixed electrodes AF3, AF4, F3, F4, F7, F8, FC5, FC6, O1, O2, T3, T4, T5 and T6 referred to the 10/20 system. The subjective annoying values (SAVs) of Signal 1 to 10 were obtained with a listening test after the EEG recording in a 5 level evaluation criterion (1 - lowest and 5 - the highest annoying level).

Table 2. The test signals

Signal	Original LFN	added pink noise	Signal	Original LFN	added pink noise
S1	LFN1		S6	LFN2	
S2	LFN1	200 Hz – 400 Hz	S7	LFN2	160 Hz – 630 Hz
S3	LFN1	200 Hz - 4K Hz	S8	LFN2	160 Hz – 2500 Hz
S4	LFN1	500 Hz - 1K Hz	S9	LFN2	400 Hz – 1600 Hz
S5	LFN1	2K Hz - 4K Hz	S10	LFN2	2K Hz - 4K Hz

The clean EEG data (removed the artifact) of seven subjects were chosen for the further analysis. The PSD was calculated for each electrode position and compared the correlation with the SAV using SPSS software. Considering the individual difference of the EEG level, relative PSD (RPSD) was calculated as the index, which was the ratio of PSD of LFN combined with bandwidth pink noise and the PSD of LFN. Due to the two different LFNs, the RPSD was obtained separately. The results showed significant negative correlation between SAV and the PSD of Alpha, Alpha1 and Alpha 2 at Frontal lobe and Temporal lobe of the cerebral cortex, which was consistent with the result of Saito [16] that changes in brain waves were reflecting the subjects' psychological response and showing their sense regarding e.g. an unpleasant sound. The Alpha wave decreased when a subject indicated discomfort. And the PSD of Beta1 at T6 was found having a significant negative relationship with SAV, which supported the result obtained from the above test. The PSD of Theta, Theta1 and Theta2 bands at T3 or T5 showed significant positive correlations with SAV, which was agreed with the similar conclusion that the increased Theta band might accompany both cognitive and emotional activation [12].

2.3 The LFN exposure combined with visual stimuli

The EEG observations in the both above tests were under the situation that there were only auditory stimuli and the subjects' eyes were closed. The conclusions obtained about the relationship between PSD of EEG bands and subjective feelings caused by LFN were overlapped. Therefore, it was necessary to detect whether the correlation between objective and subjective parameters would be consistent when there were not only LFN but also other sensory stimuli. LFN (40 dBA) in an approximate slope of -4 dB/octave spectral characteristic was used in this test, which was the common spectrum form according to the measurement results of 29 wind turbines in Japan [17]. Eight different field recordings of wind turbines in Zetel of Lower Saxony in Germany were the visual components (Table 3), which included different blade rotating speeds and wind turbine surrounded with some landscapes. The test signals were the LFN combined with different visual contents. The subjects set in front of a monitor and loudspeakers, and gave their annoyance assessment after each signal in a five level criterion ("1" for not annoying at all and "5" for very annoying). EEG was recorded with Neuro-Spectrum-5 equipment during the whole test at AF3, AF4, T3, T4, O1 and O2 positions, additionally EOG at left and right sides of the eyes were also collected. The duration of each signal was 1 min and 30 seconds pause in silence between two signals. There were three reference stages before the test signals, which were baseline without LFN and visual stimulus, only with LFN and only with visual stimulus (wind turbine in normal blade rotating speed).

Table 3. The signals in the test (N = normal blade rotating speed)

Signal 1	Signal 2	Signal 3	Signal 4
Slow speed	hidden by trees (N)	Fast speed	with several cows (N)
Signal 5	**Signal 6**	**Signal 7**	**Signal 8**
Normal speed	90° side (N)	several WTs (N)	Still

Besides the same “Noise Sensitivity”, “GHQ-28”, “PANAS” questionnaires, the subjects were asked to answer a basic “Hearing Problems” questionnaire, which was used to check whether the subjects had slightly hearing damage. Since this test was related to wind turbines and the attitude to wind turbine was considered as an influent aspect for the perception of the emitted noise, an overall opinion to wind turbine and five specific questions were investigated. The PSD results of fourteen subjects were calculated, and the RPSD, which was the ratio of the signals PSD and the reference PSD (reference = baseline stage without LFN and visual stimulus), was used to compare with the subjective results (SAV) like the above test. Differences among question groups were also summarized.

The RPSD of Beta, Beta2 band at T3 showed a significant negative correlation with the average SAV for all subjects, which was agreed with the conclusion obtained in the other tests. Another similar finding was that the significant positive correlation between the PSD of Theta1 band at AF4, T3 and the SAV result. However, the positive relationship between RPSD of Alpha band at AF3 and SAV was in an opposite trend compared with the last test. The inconsistency might due to the additional visual stimuli, which were required the subjects to open their eyes during the test, and Alpha energy decreased obviously when eyes opened.

3. The effects of psychological questionnaires

The emotional activation was found that it could produce measureable effects on the EEG, therefore, it was hypothesized that personality traits would interact with the strength [12].

Noise sensitivity was an important aspect in the researches related with noise exposure. Some evidence suggests that 19% of the population is “more sensitive” than “average”. Stansfield recognized that noise sensitivity was a factor between noise exposure and annoyance, and he concluded “the most potent predictor of noise annoyance, apart from noise level, is noise sensitivity which is also associated with psychiatric disorder” [18]. The individual sensitivity to noise was also probably relative to the time generating steady stress responses [5]. The indirect method, using additional bandwidth pink noise to decrease the negative annoying feelings caused by LFN, was found more suitable for subjects with high noise sensitivity [15]. The results in this paper indicated that subjects with different noise sensitivity levels they gave different subjective annoyance evaluations for LFN and LFN with additional auditory or visual stimuli, and the PSD changes of Beta band along time showed well relevant with the differences among the noise sensitivity groups.

The GHQ-28 was used as an indicator of psychological well-being [10]. When compared the PSD results of subjects with different GHQ – 28 scores, the PSD at Frontal and Temporal lobes showed obvious differences in all EEG bands. PANAS was one of the most widely used scales to measure mood or emotion, and the difference by the subtraction of negative from positive score showed that this self-reported personality stats and traits had a significant correlation with the left and right hemispheric ratio at Frontal lobe, which was related with stress.

4. Conclusions

EEG reactions under LFN exposure in different situations were summarized. The PSD of EEG bands were compared with the subjective annoyance level caused by LFN and PN, or LFN combined with different bandwidth PN, or LFN with visual stimuli. The PSD of Beta band at Temporal lobe showed a significant negative correlation with the subjective annoyance evaluation and the variation of Beta band along time was similar under PN exposure, but in an obvious different form under LFN exposure. And the PSD of Theta, Theta1 or Theta2 bands at Frontal or Temporal lobe were found a significant positive correlation with the SAV results. These findings were consistent in all tests, but the relationship between the PSD of Alpha band and subjective annoyance result was not always the same. It was negative with only auditive stimuli affecting and was positive with auditive and simultaneous visual stimuli, which might be caused by the different types of the external stimuli.

Besides the conclusions above, the effects of different psychological questionnaires on the EEG test related with LFN were also discussed. The PSD results of the subjects with different GHQ-28 or PANAS scores showed statistical difference, which means that the questions about mental performance or self-reported emotional state can give effective help for understanding the brain reaction under LFN exposure. Noise sensitivity was found important in the tests, which was reflected by the obvious different subjective evaluation and EEG variation results.

The above-mentioned findings demonstrated that EEG was effective for objective evaluation as a physiological index. And EEG could be useful for the further exploration of low frequency noise sufferers.

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