# The EEG variation caused by the LFN

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## ABSTRACT

In this paper a preliminary pilot EEG test is described that was conducted to study the reason why low frequency noise (LFN) is more annoying than other kinds of noise (pink noise was used as the compared noise). A special noise sensitivity showed an influence on people's perception of LFN and annoyance. The power spectral density (PSD) of Theta, Alpha or Beta bands in the auditory area of the cerebral cortex showed clear differences between subjects with high and those with normal noise sensitivity, and it also showed a correlation with the annoyance caused by LFN or pink noise. Using a subjective evaluation test and an EEG-recording, the possibility was investigated to reduce the LFN-caused annoyance by adding of pink noise with different bandwidths. The results indicated a significant correlation between the annoying levels caused by LFN combined with the additional noise and the PSD of Theta or Alpha bands.

## INTRODUCTION

Low frequency noise (LFN) has been proven more annoying than other kinds of noise (Kjellberg et al., 1984; Pawlaczyk-Luszcynska et al., 2002). The exact reason why a certain part of people has serious problems with LFN is unknown, and the relevant studies have been done on the hearing aspect (Pedersen, 2008; Krahé, 2009), and the brain (Krahé & Weigler, 2013). An important and unique characteristic of LFN is difficult to locate the noise sources. Sometimes LFN can be heard not only by the sufferers, but also by other people. But many situations are that LFN can only be heard and unacceptable by the sufferers, and impossible to determine the noise. Therefore, it is difficult to reduce LFN from the source, and the coping strategies related with LFN sufferers should be more effective. An indirect method, sound adjustment (Li, 2012) for example, seems to be more feasible as a new coping strategy for LFN. Many studies suggested that the subjective annoyance caused by LFN can be influenced by adding some additional sounds (Di et al., 2011; Li, 2012), and the presence of higher frequency sounds was found effective to reduce the influence of LFN (Salt & Lichtenhan, 2012).

With the development of the technology, EEG has become a useful tool to observe how a person's brain reacted to music (Iwaki et al., 1997; Schmidt & Trainor, 2001), noise (Landström et al., 1985; Damijan & Wiciak, 2007), and related to the disturbance of noise on sleep (Inaba & Okada, 1988).

There are three tests in this paper. The first one is a pilot EEG test, with the goal to prove the possibility that the brain changes under different noises are significant, and there is relationship among subjective annoyance caused by LFN, noise sensitivity and EEG parameters. The second part is a subjective evaluation hearing test, which shows the feasibility of the indirect method to reduce the annoyance caused by LFN. The last part is to observe the EEG variation during the indirect method, and to find

out the statistical correlation between subjective annoying value (SAV) and EEG parameters.

## THE PILOT EEG TEST

The pilot EEG test was faced to three male subjects. They answered the noise sensitivity questionnaire (NS) (Schutte et al., 2007), GHQ-28 (Nagyova et al., 2000) and PANAS (Watson et al., 1988) before the EEG test. LFN used in this test was the Brown noise through Butterworth low pass filter with the cut-off frequency at 125Hz and the order 10. The reference noise was pink noise (PN) with frequency range from 20 Hz to 20000 Hz. Both noises were set to 50 dBA in 5 minute duration and presented with loudspeakers in a chamber with low background noise level. The subjects were sitting in front of the loudspeaker with a 1.5 m distance, and asked to keep still with their eye closed during the whole EEG recording. A procedure of the test is shown as in Figure 1. After the EEG test, the subjects were investigated their annoyance feelings about LFN and the reference noise, and the more annoying one was with a higher subjective annoying value (SAV). The EEG equipment was the BIOPAC MP150 with 125 Hz as the sample frequency, and the electrode position was T8 according to the 10/20 system (Jasper, 1958), which was the auditory area of the cerebral cortex.

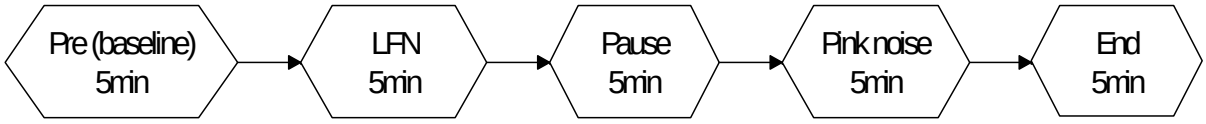


**Figure 1**: The process of the pilot EEG test

The EEG data was analyzed with EEGLAB to remove the artifacts. And the power spectral density (PSD) of Theta band (4-7 Hz), Alpha band (8-13 Hz) and Beta band (14-30 Hz) were calculated in MATLAB. Considering the individual difference of the EEG level, the relative PSD (RPSD) was calculated as the index, which was the ratio of the PSD in each segment to the reference PSD. The reference PSD was the average PSD value of the baseline segment. Table 1 is the basic information of the subjects, the results of questionnaires and EEG data.

**Table 1**: Three subjects' results of questionnaires and EEG data

| Subject | Gender | Age | NS | SAV | GHQ-28 | PANAS | EEG result | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Theta | Alpha | Beta |
| P1 | M | 30 | Yes | LFN>PN | 35 | 23 | LFN<PN | LFN<PN | LFN<PN |
| P2 | M | 27 | No | LFN≈PN | 33 | 19 | LFN>PN | LFN≈PN | LFN≈PN |
| P3 | M | 31 | No | LFN<PN | 35 | 23 | LFN>PN | LFN>PN | LFN<PN |

Figure 2 is the RPSD results. Comparing with the results in Table 1 the RPSD value of Alpha band showed a negative relationship with SAV. And it was consistent with the result that changes in brain waves depended on the subjects' psychological response, whether they regarded a sound as unpleasant, and the Alpha wave decreased when a subject indicated discomfort (Saito, 1988). Noise sensitivity showed an important factor for annoying feelings caused by LFN and for the EEG changes. For example, for P2 and P3, who were not sensitive to noise, the Alpha power was lower after the segments for noise. However, for P1, who was sensitive to noise, the Alpha power after noise exposure rose. The Theta power also showed

difference at last two segments between subjects with high and with normal noise sensitivity. The different PSD value among the five segments indicated that there were different brain changes at auditory area of the cerebral cortex, when people were exposing under different noises.

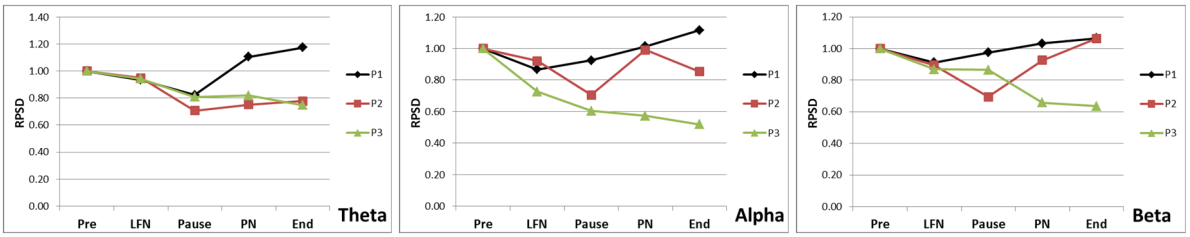


**Figure 2**: The RPSD results of Theta, Alpha and Beta bands

## SUBJECTIVE EVALUATION LISTENING TEST

The subjective evaluation listening test was made with 16 students from Capital Normal University in China (He et al., 2014). There were 4 original LFN samples with 45 dBA level in this test. LFN1 was recorded from a heat pump unit in the center of an office (Di et al., 2011). LFN2 was recorded in an apartment whose owner suffered from LFN. LFN3 and LFN4 were generated from software, which were filtered from the same Brown Noise. LFN3 (BN-80 Hz) was the Brown Noise through Butterworth low pass filter with the cut-off frequency at 80 Hz and the order 10, and LFN4 (BN-160 Hz) was obtained with the same filter but with 160 Hz as the cut-off frequency. Pink noise and white noise in different bandwidth frequency ranges were used as the additional sounds. The SPL of the pink or white noise was set to 15 dB, 20 dB and 25 dB. Table 2 is the frequency information of the additional noises and Table 3 is the signal arrangement of the six sub-tests. The duration of each noise sample was 5s, with an interval of 3s, and the signals were presented via loudspeakers.

**Table 2**: The frequency ranges of the additional pink noise or white noise

| | | |
|---|---|---|
| 250-500 Hz | 250-4K Hz | 1K-2K Hz |
| 250-1K Hz | 500-1K Hz | 2K-4K Hz |
| 250-2K Hz | 500-2K Hz | 4K-8K Hz |

**Table 3**: The information of the six sub-tests in the study

| Test 1 | Test 2 | Test 3 |
|---|---|---|
| LFN1 + Pink noise | LFN1 + White noise | LFN2 + Pink noise |
| Test 4 | Test 5 | Test 6 |
| LFN3 + Pink noise | LFN4 + Pink noise | LFN4 + White noise |

Firstly the subjects answered the same noise sensitivity questionnaire as in the last test, and were classified into noise sensitive group (SG) and non-sensitive group (Non-SG). The subjects were asked to evaluate the annoying feelings in a seven annoying levels range, 1 was the lowest and 7 was for the highest. The SAV of each original LFN was set to 4 in every sub-test and presented always as the first signal with a given annoyance level value on the test tables and repeated several times. Table 4 is the average SAV results. The SAVs of the SG were lower than the Non-SG, when the additional components were pink noise. And the result was opposite with white noise as the additional noise that the SAVs of the SG were higher, which indicated that subjects with different noise sensitivity had different subjective annoying feelings caused by LFN combined with pink noise or white noise. Figure 3 shows two examples of the results.

**Table 4**: The average SAV results

| | Non-SG | SG | | Non-SG | SG |
|---|---|---|---|---|---|
| LFN1-PN | 4.48 | 4.18 | LFN3-PN | 4.66 | 4.23 |
| LFN1-WN | 4.38 | 4.75 | LFN4-PN | 4.36 | 4.65 |
| LFN2-PN | 4.66 | 4.31 | LFN4-WN | 4.31 | 4.58 |

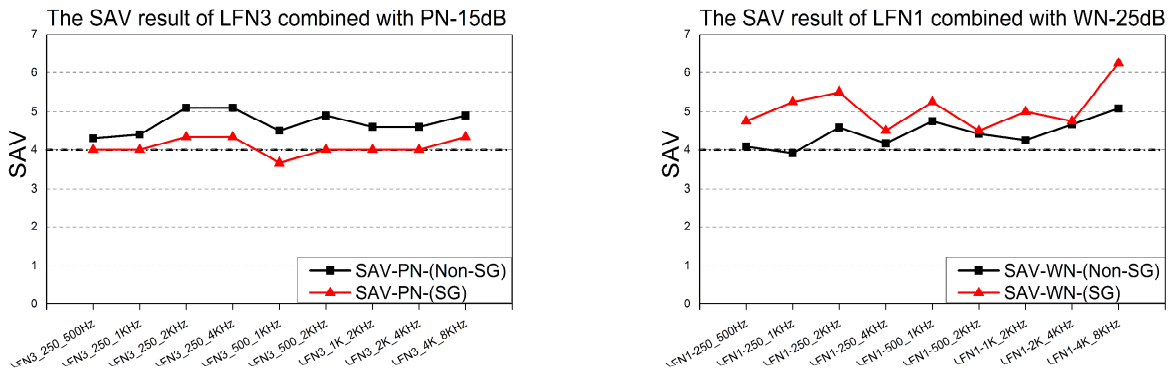


**Figure 3**: The example of SAV results of two noise sensitive groups

The SAVs of LFN1 combined with pink noise and with white noise were almost the same for the Non-SG, but the SAVs of LFN1 combined with pink noise were significant lower than the SAVs of LFN1 combined with white noise for the SG (Figure 4). And the SAVs of LFN with pink noise in the middle frequency range were found lower than the SAV of the original LFN, which mostly happened in the SG. This result indicated that people with high noise sensitivity were influenced more positively than people with normal noise sensitivity, when bandwidth pink noise was used as the additional components. And it also implied that this indirect method was possibly more suitable to decrease the negative annoyance feelings caused by LFN for people with high noise sensitivity, but not for the people with normal noise sensitivity.

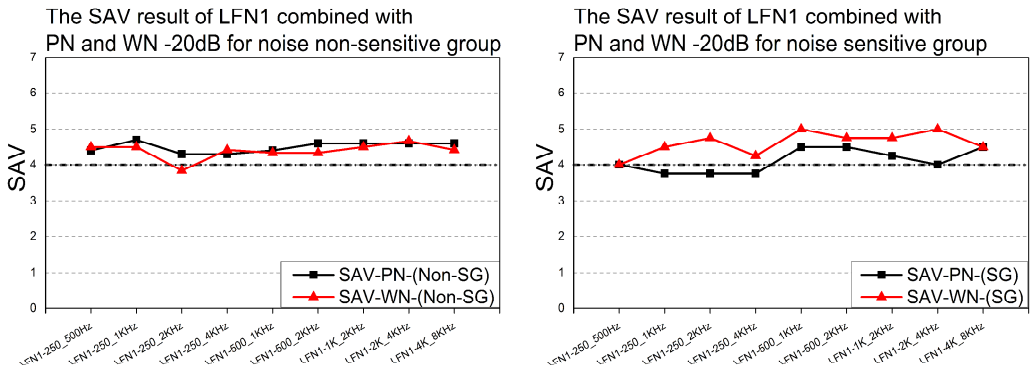


**Figure 4**: The SAV results of adding pink noise and white noise for two noise sensitivities

## THE COMBINATION TEST WITH INDIRECT METHOD AND EEG

In this test the same indirect method was repeated with 20 German subjects from Wuppertal University, and the brain reaction was observed by EEG in the same time. Two LFNs from the last subjective listening test were selected for the test, which were LFN1 and LFN4. The level of the LFNs was set also at 45 dBA, and the

additional sounds here were bandwidth pink noise in 20 dB according to the result of last test (He et al., 2014). Table 5 is the detail of the 10 stimuli in this test.

**Table 5**: The information of the signals in the test

| Signal | Original LFN | added pink noise | Signal | Original LFN | added pink noise |
|---|---|---|---|---|---|
| S1 | LFN1 | | S6 | LFN4 | |
| S2 | LFN1 | 200 Hz – 400 Hz | S7 | LFN4 | 160 Hz – 630 Hz |
| S3 | LFN1 | 200 Hz - 4K Hz | S8 | LFN4 | 160 Hz – 2500 Hz |
| S4 | LFN1 | 500 Hz - 1K Hz | S9 | LFN4 | 400 Hz – 1600 Hz |
| S5 | LFN1 | 2K Hz - 4K Hz | S10 | LFN4 | 2K Hz - 4K Hz |

After the reliable calculation only 10 subjects' results were used (6 male and 4 female) for the following analysis. The subjects first answered the same noise sensitivity and GHQ-28 questionnaires as mentioned in the pilot EEG test. But none of them got high noise sensitivity score. Therefore, they were only classified into two groups according to the GHQ-28 score. Three subjects who got the score of GHQ-28 more than 23 (include 23) were classified to GHQ-Group1 (with poor psychological well-being), and the other seven subjects with score lower than 23 belonged to GHQ-Group2.

The Emotiv EEG neuroheadset with 14 fixed electrodes, AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, and AF4 according to the 10/20 system was used in the test. In the EEG recording test the subjects were listening to the stimuli with the sequence from S1 to S10, the loudspeakers and other requirements were the same as in the pilot EEG test. The listening test was then made with the same stimuli in a random order, and the annoying levels the subjects needed to evaluate were from 1 to 5, 1 was lowest and 5 was the highest annoying level.

The average SAV was obtained, and the values of LFN combined with pink noise in middle frequency range were found lower than that of the original LFN, which consisted with the previous result. The EEG data was analyzed similar as in the pilot EEG test. Firstly, the absolute PSD value of Theta, Alpha and Beta bands were calculated, and the differences between the subjects exposed to LFN and to LFN combined with bandwidth pink noise were compared. The Wilcoxon test results showed that the differences were significant for the most subjects, which indicated that LFN combined with bandwidth pink noise could cause the changes of people's subjective annoying feelings and also related brain variation. Secondly, the RPSD was obtained from the ratio of the PSD of LFN combined with bandwidth pink noise to the PSD of the original LFN, and then the correlation between SAV and RPSD of Theta, Alpha and Beta bands were calculated (Table 6). The SAV showed a significant positive relationship with RPSD of Theta band and negative correlation with RPSD of Alpha band, which correspond with the result of the pilot EEG test.

**Table 6:** The correlation coefficient between SAV and RPSD value

| | Correlation Coefficient | Sig. (2-tailed) |
|---|---|---|
| Theta band | ***.753*** | ***.012*** |
| Alpha band | ***-.643*** | ***.045*** |
| Beta band | -.625 | .053 |

In addition the correlation between SAV and RPSD of Theta, Alpha and Beta band for each electrode position were also checked. The significant correlation result was individual, but the universal electrode positions were cerebral cortex areas related with sound processing and adverse emotional inhibition. Another finding was that the visual function area was shown correlation with the annoyance variation caused by auditory stimuli, and some subjects also reported that they had visual changes during the test.

In the end Independent-Samples test was calculated to find out the difference between two GHQ groups and between male and female subjects. The SAV of GHQ-Group1 was average higher than that of the GHQ-Group2, but the result was not significant. The RPSD value of Alpha band for the GHQ-Group2 was significant higher than that of the GHQ-Group1. These results indicated that subjects with poor psychological well-being got more annoying feelings, and their Alpha wave power changed in a larger range. The gender factor was significant that the SAV of the female subjects was higher than that of the male subjects.

## CONCLUSION

The EEG variation caused by LFN was investigated. Theta and Alpha band power were found significant relationship with the subjective annoyance feelings and judgement for LFN, which was consisted with previous conclusions. The indirect method, adding bandwidth pink or white noise was proven the possibility to reduce the subjective annoying feelings caused by LFN. Pink noise in middle frequency range seemed more suitable than other frequency to use as the addition component for this method, and the maximum reduction of SAV had 18.25%. Through the tests noise sensitivity was found important for the study related to LFN and EEG. Noise sensitivity is an important non-acoustical factor in the determination of reactions to noise and is a major antecedent of annoyance reactions (Job 1988). The SAV reduction for subjects with high noise sensitivity was found greater with the indirect method, in contrast the SAV of LFN combined with pink or white noise was mostly higher than the SAV of original LFN for subjects with normal sensitivity. It indicated the suitability for the indirect method to help high noise sensitive people to reduce their negative annoying feelings caused by LFN. And the EEG changes were also different among subjects with different noise sensitivity. Similarly, subjects with different GHQ-28 scores also showed different annoyance reaction and EEG variation.

There were only university young students as the subjects in the tests, and most of them didn’t experience or suffer LFN at the normal life. Therefore, it is more meaningful to use LFN sufferers as the subjects for the later experiments, and to find out the reason why they have different feelings from LFN. EEG will be the main tool for observing the influence caused by LFN on people, so questionnaires such as PANAS and PSS, which are often used in EEG research, will also need to consider in the further experiments.

## REFERENCES

Damijan, Z., and Wiciak, J. (2007). The influence of low frequency sound on the changes of EEG signal morphology. Molecular and Quantum Acoustics 28: 65-70.

Di, G., Li, Z., and Zhang, B.et al. (2011). Adjustment on subjective annoyance of low frequency noise by adding additional sound. J Sound Vib 330: 5707-5715.

He, M., Deng, ZY., Krahé, D. (2014). The subjective influence of the LFN combined with pink and white noise. The 40th Annual German Congress on Acoustics (DAGA) (Oldenburg,Germany)

Inaba, R., and Okada, A. (1988). Study on the effect of infra- and low frequency sound on the sleep by EEG recording. Journal of Low Frequency Noise and Vibration 7: 15-19.

Iwaki, T., Hayashi, M., and Hori, T. (1997). Changes in alpha band EEG activity in the frontal area after stimulation with music of different affective content. Perceptual and Motor Skills 84: 515-526.

Jasper, H. (1958). The 10-20 electrode system of the International Federation. Electroen Clin Neuro 10: 370-375.

Job RFS. (1998). Community response to noise: a review of factors influencing the relationship between noise exposure and reaction. J Acoust Soc Am 83: 991-1001.

Kjellberg, A., Goldstein, M., and Gamberale, F. (1984). An assessment of dBA for predicting loudness and annoyance of noise containing low frequency components. Journal of Low Frequency Noise and Vibration 3: 10-16.

Krahé, D. (2009). Reflection of LFN perception on an Auditory Model. NAG/DAGA International Conference on Acoustics (Rotterdam).

Krahé, D., and Weigler, T. (2013). Reaction in the brain to low-frequency noise. AIA-DAGA 2013 (Merano, Italy).

Landström, U., Byström, M., and Nordström, B. (1985). Changes in wakefulness during exposure to noise at 42Hz, 1000Hz and individual EEG frequencies. Journal of Low Frequency Noise and Vibration 4: 27-33.

Li, Z. (2012). Study on acoustical simulation and adjustment methods of subjective perception and objective law of electroencephalogram variation under noise exposure. (Zhejiang University).

Nagyova, I., Krol, B., and Szilasiova, A.et al. (2000). General health Questionnaire-28 psychometric evaluation of the Slovak version. Studia Psychologica 42: 351-361.

Pawlaczyk-Luszcynska, M., Dudarewicz, A., and Waszkowska, M. (2002). Annoyance of low frequency noise in control rooms. Proceedings of the International Congress and Exposition on Noise Control and Engineering (Mi. USA).

Pedersen, C. S. (2008). Human hearing at low frequencies with focus on noise complaints. (Aalborg University, Denmark).

Saito, K. (1988). Effect of noise on higher nervous activity. J Sound Vib 127: 419-424.

Salt, A. N., and Lichtenhan, J. T. (2012). Perception-based protection from low-frequency sound may not be enough. Proceedings InterNoise .

Schmidt, L. A., and Trainor, L. J. (2001). Frontal brain electrical activity (EEG) distinguishes valence and intensity of musical emotions. Cognition and emotion 15: 487-500.

Schutte, M., Marks, A., and Wenning, E.et al. (2007). The development of the noise sensitivity questionnaire. Noise & Health 9: 15-24.

Watson, D., Clark, L. A., and Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: the PANAS scales. J Pers Soc Psychol 54: 1063-1070.