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Impact of road traffic noise on functional connectivity of human brain networks

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Abstract. With the rapid economic development, the rapid increase in motor vehicle holdings, a sharp increase in urban road traffic, road traffic noise exposure is becoming increasingly serious. This paper focuses on the impact of traffic noise exposure on the human brain. We collected road traffic noise sounds of different sound pressure levels (SPLs), and recorded the electroencephalograph (EEG) when subjects exposed under different SPLs' road noise. Using the graphic theoretical-based EEG method, the effects of road traffic noise with different SPLs on the functional connectivity of human brain networks were studied. Using time-frequency analysis, the beta2 bands was found to be most sensitive frequency band to different SPLs road noise. The brain network characteristic parameters of different SPLs noises were calculated. It is found that in these two frequency bands, the higher the noise SPL, the lower the clustering coefficient and the higher the characteristic path length. In summary, the paper points out the specific effects of road noise with different SPLs on the human brains. It is found that the higher the SPL of noise, the greater the damage to the functional connectivity of the human brain. That means, noise exposure can affect the rate at which the brain processes, analyses, and transmits information. The research results can provide a basis for road noise evaluation and prevention.

1. Introduction

Road traffic noise refers to the sound produced by motor vehicles on the road that exceeds the national standard. According to the "Acoustic Environmental Quality Standards" (GB3096-2008), the road noise limit is 70dB and the night noise limit is 55dB. With the rapid increase in the number of motor vehicles, the traffic volume in the city has increased sharply. The noise pollution rate of residential buildings, schools and hospitals on both sides of the road in Beijing alone has reached 89.1%. And the noise pollution rate on both sides of the expressway has reached 100%. Long-term exposure to noisy environment can have many adverse effects on health, such as emotional annoyance, increased stress, distraction, unresponsiveness, and even cardiovascular and cerebrovascular disorders [1-3]. Traffic noise exposure has become the fourth risky environmental factor affecting health in Europe. Road traffic noise has become a special public health problem in urban environments. So this paper proposes to study the effects of noise exposure on the functional connectivity of the human brain.

The existing researches aimed at road traffic noise are less, and many of them focuses on the study of the impact of traffic noise on sleep quality [4, 5]. In this paper, the innovative use of complex brain function connection network is an in-depth study of the effects of urban road traffic noise exposed to different sound pressure levels (SPLs) on the human brain in daily life. The frequency bands sensitive

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to noise in the human brain were found, and a complex network of brain functions was constructed. Based on the graph theory, the network characteristic parameters sensitive to noise exposure were found. Statistical methods were used to statistically analyze the changes of various characteristics under the noise exposure of different SPLs, and to extract the feature quantity that most directly reflected the influence of noise exposure on the human brain.

2. Experiments and Methods

2.1. Experiments

Thirty subjects (18 males, 12 females, and aged 23-65 years old). They are all healthy and no sleep-related diseases. They are all with good hearing, and did not have any alcohol, coffee or drugs within 48 hours before the experiment. All subjects agreed to participate in the experiment and received a certain amount of compensation.

Using the ASV5910 sound meter, the noise source signals were collected and recorded for 6 minutes in a quiet area with a sparse traffic flow at night (about 50 dB), a normal traffic at noon (about 70 dB), and a dense peak traffic (about 90 dB). Studies have shown that noise exposure over 5 minutes produces a phenomenon of EEG that is significantly associated with subjective evaluation [6].

The subjects' EEG signals were collected by a portable EMOTIVEPOCH with a sampling frequency of 128 Hz. There are totally 14 electrodes, following the international standard of 10-20 system. Besides, the reference electrode was located in the bilateral posterior mastoid.

The experiment was carried out in a quiet, dimly closed room. The SPA2340 active speakers were used to play three sound sources. The speakers were placed at a fixed position about 1 m away from the subject's ears and the volume remained constant. The subject sat in a comfortable office chair and wore an electrode cap. Firstly, the EEG signal in the resting state (about 35dB) of each subject was recorded for 1min. Then three kinds of noises were randomly played in six groups (each kind of noise was played twice), each group was 6min in length. And between each group of tests, subjects were asked to take a rest for 30min to eliminate the impact of previous noise on the subject.

2.2. Methods

Here, the cross mutual information (CMI) is used to calculate the correlation between the nonlinearities of any two channels [7].

Suppose that F_i is used to represent the average power spectrum of the *i*th channel, and $p\ (F_{i,b})$ is used to represent its probability density function. The information entropy of F_i uses H (F_i) as follows, where N is the number of random states that the variable F_i has, and N is 40. $P\ (F_{i,b})$ is the probability density function for each state.

$$\mathrm{H}(F_i)=\sum_{b=1}^{N} p(F_{i,\mathrm{b}})\log_2 p(F_{i,\mathrm{b}}) \tag{1}$$

And the joint entropy of the channel *i* and *j* is defined as:

$$\mathrm{H}(F_i,F_j)=\sum_{b=1}^{50} p(F_{i,\mathrm{b}},F_{j,\mathrm{b}})\log_2 p(F_{i,\mathrm{b}},F_{j,\mathrm{b}}) \tag{2}$$

Where $p(F_{i,b}, F_{j,b})$ is the common probability density function for $F_{i,b}$ and $F_{j,b}$.

The mutual information of the two leads is defined as the following formula, and the wavelet transform is brought in

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$$\mathrm{MI}(F_i, F_j) = \mathrm{H}(F_i) + \mathrm{H}(F_j) - \mathrm{H}(F_i, F_j) = \sum_{b=1}^{50} p(F_{i,\mathrm{b}} \mid F_{j,\mathrm{b}}) \ln \frac{p(F_{i,\mathrm{b}}, F_{j,\mathrm{b}})}{p(F_{i,\mathrm{b}})\, p(F_{j,\mathrm{b}})} \quad (3)$$

3. Results and discussions

The EEG data obtained from the time-frequency analysis and the time series of the noise decibel value are cross-inter-informed to find the frequency interval highly correlated with the noise sound pressure level. As shown in Fig. 1, the beta2 band (20-30Hz) is most significant.

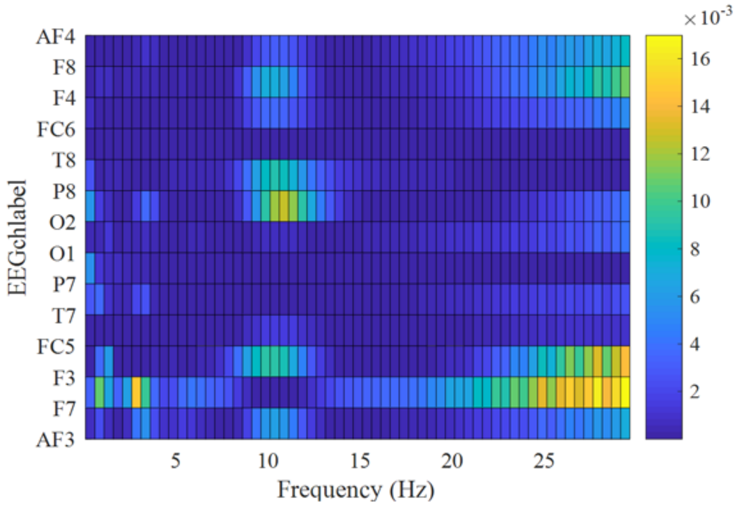
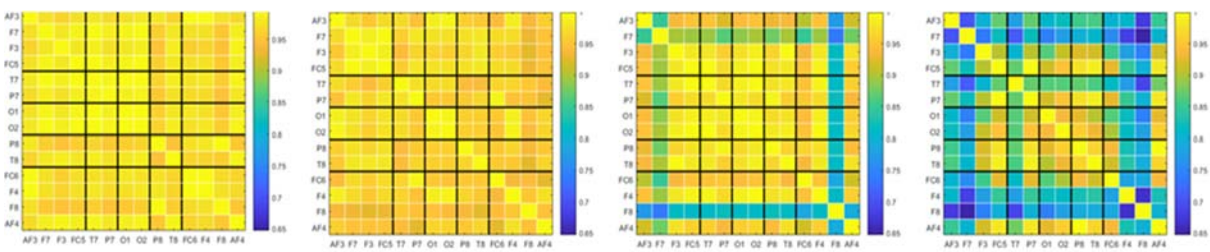


Figure 1. Time-frequency spatial map of the cross-mutual.

Furthermore, a complex network based on graph theory was used to analyze the state of brain function network in each state. Based on Equ. 3, we calculated the MI values of each two channels, and constructed time-frequency mutual information correlation matrices. Fig. 2 shows the brain function connection network adjacency matrix in each state of the beta2 band. It is observed that the greater the SPL of the noise, the worse the network connectivity.



(a) Rest (b) 50Hz (c) 70Hz (d) 90Hz

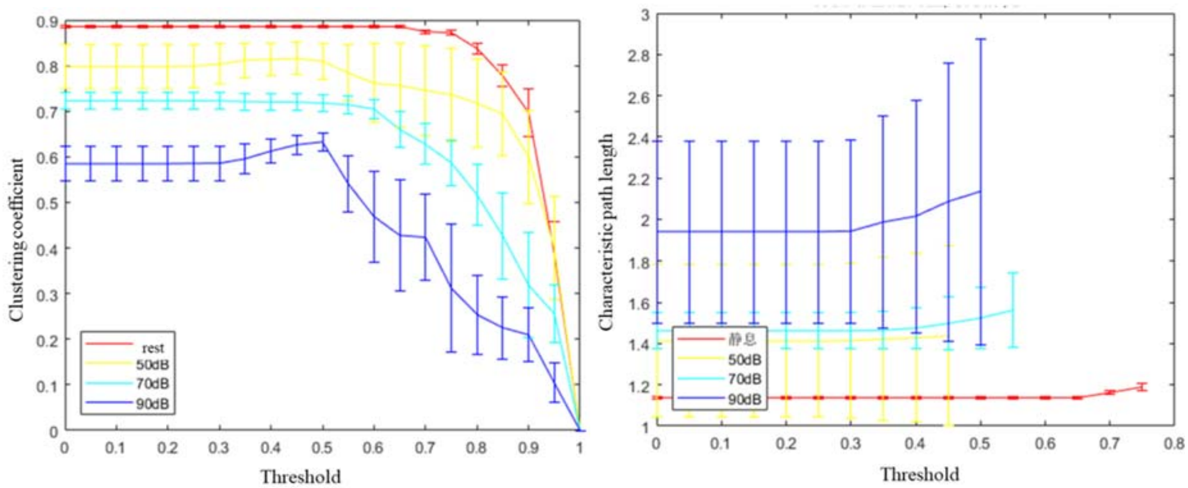
Figure 2. The brain function connection adjacency matrix of the subjects in each state.

Based on the graph theory, the characteristic parameters of the brain functional connection network matrices—the clustering coefficient and the characteristic path length of different thresholds [8] were calculated. The results are shown in Fig. 3. The characteristic parameters of the brain function connectivity network in the beta2 band vary with the threshold. As shown, the SPL of noise increases can lead to a decrease in the clustering coefficient and an increase in the characteristic path length. It can be seen that the noise with higher SPL can lead to the deterioration of the connectivity of the brain function connection network. That is, the efficiency of the brain processing and transmitting information is reduced.

Then we did statistical analysis with the parameters under different SPLs. As results shown in Table 1, there are significance changes in both parameters.

Table 1. The most significant threshold of each parameters.

	Clustering coefficient	Characteristic path length
p value	th=0.65** p=6.53e-7<<0.01	th=0.45** p=1.97e-4<<0.01



(a) clustering coefficient (b) characteristic path length

Figure 3. Curve of brain function connection network parameters with threshold value in each state of beta2 band

4. Conclusion

In this paper, we use the time-frequency cross-mutual information method to find out the frequency band beta2 which has a significant response to the road noise level, and construct a brain-complex connection network based on graph theory. The network characteristic parameters are extracted, and the variation of characteristic parameters under different noise level highway noise is observed. It is found that when the road noise level increases, the clustering coefficient of brain network characteristic parameters decreases, the characteristic path length increases and the global efficiency decreases. The study has shown the specific impact of road noise on the functional connectivity of human brain networks.

Acknowledgments

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