Optimization of PTSD disorder detection based on nonlinear dynamic analysis of electroencephalogram signals

Optimización de la detección de trastorno de trastorno de estrés postraumático basada en análisis dinámico no lineal de señales de electroencefalograma

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Abstract

Objective: Post-traumatic stress disorder (PTSD) is an emotional disorder. This paper aimed to examine the entropy values in patients with PTSD disorder. Methods: The entropy values of 31 EEG channels of 12 subjects (six healthy subjects and six patients with PTSD disorder) with two entropy methods (sample entropy and fuzzy entropy) were calculated. Results: The sample entropy of channels FP1, FP2 and FC6 and fuzzy entropy of channel FC6 were increased in PTSD group and had the highest difference in compare to healthy group. In addition, sample entropy method showed superiority in compare to fuzzy entropy for PTSD recognition problems. Conclusion: Compared to normal group, patients with PTSD disorder were found to have average increased entropy values. Results showed that EEG signals of subjects with PTSD disorder had higher irregularity due to entropy increments. This entropy increment is more obvious in frontal lobe of the brain which related to emotional experiences.

Keywords: PTSD, EEG

Resumen

Objetivo: El trastorno de estrés postraumático (TEPT) es un trastorno emocional. Este documento tuvo como objetivo examinar los valores de entropía en pacientes con trastorno de trastorno de estrés postraumático. Métodos: Se calcularon los valores de entropía de 31 canales de EEG de 12 sujetos (seis sujetos sanos y seis pacientes con trastorno de TEPT) con dos métodos de entropía (entropía de muestra y entropía difusa). Resultados: La entropía de muestra de los canales FP1, FP2 y FC6 y la entropía difusa del canal FC6 se incrementaron en el grupo con TEPT y tuvieron la mayor diferencia en comparación con el grupo sano. Además, el método de entropía de muestra mostró una superioridad en comparación con la entropía difusa para problemas de reconocimiento de TEPT. Conclusión: en comparación con el grupo normal, se encontró que los pacientes con trastorno de trastorno de estrés postraumático tenían valores de entropía aumentados promedio. Los resultados mostraron que las señales de EEG de los sujetos con trastorno de trastorno de estrés postraumático tenían una mayor irregularidad debido a los incrementos de entropía. Este incremento de entropía es más obvio en el lóbulo frontal del cerebro que se relaciona con las experiencias emocionales.

Palabras clave: PTSD, EEG

Introduction

EEG (Electroencephalogram) signal contains voltage of temporal variations that reflects brain electrical activity[1]. The EEG signals holds important electrophysiological information about the brain's activity during different user states. Analyzing EEG signals in different states or various brain disorders is an important area of biomedical research[2,3].

In the past decades, only a few studies focused on EEG analysis in patients with PTSD disorders. The existence of abnormalities in PTSD have been reported through event-related potential (ERP) analysis[4-9]. Wolf et al.[10] investigated the EEG activity of PTSD patients in two states of sleep and waking and find that all EEG signals in both states (sleep and awake) were within normal limits. Conventional spectral analysis proved that theta activity over central regions and beta activity over frontal part of the brain had increased for patients with PTSD disorders[11,24]. Jeong-Ho Chae et al.[12] found that Correlation dimension of EEG signals for PTSD patients decreased in channels Fp1, F8, C4, P4, T3, T4, T5, T6 and O1. Non-linear independence (NI) values of EEG signals from 16 PTSD and healthy subjects were measured and results showed increment of NI value in channels F3, F7, C3, T5 and P3 and decrement in in channels F4, C4, P4, and O2[13,21].

Due to nonlinear dynamic nature of the brain, advanced signal processing methods are required to extract nonlinear dynamic features from EEG signals. Entropy value of EEG signal is a great tool for measuring irregularity of given signals. In this paper, we aim to calculate entropies of different EEG channels with two most known entropy methods to see which EEG channels plays more effective role in PTSD detection problems.

The structure of this paper is as follow. Section 2 of this paper is for database explanation. The proposed method is explained in section 3. Results come in Section 4 and finally conclusion is discussed in section 5.

Database: In this paper we have used available database which was provided by Laureate Institute for Brain research as part of a simultaneous EEG study[14]. The database contains EEG and ECG signals of six patients with PTSD disorders and six healthy subjects. The EEG recorded from 31 channels (Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T7, T8, P7, P8, Fz, Cz, Pz, Oz, FC1, FC2, CP1, CP2, FC5, FC6, CP5, CP6, TP9, TP10, POz) with resolution of 0.1 micro-volt and sampling frequency of 5000 samples/s. By using independent component analysis (ICA), blink and saccade artifacts and residual cardio ballistic artifact, were removed from original EEG signals and then down sampled to 250 sample/s (4 ms temporal resolution). A low pas filter was applied to 40Hz. For each EEG channel there were 131500 samples (526 second). The first 6 second steady state was removed and for further analysis only first available 50000 samples were selected which had no subject motion.

Methods

Sample and Fuzzy entropy

Entropy is index of irregularity of a signal[15]. Higher entropy value indicates higher complexity and less regularity in a given signal. Among various proposed method for entropy calculation, sample entropy and fuzzy entropy are the two most used methods in the entropy analysis of physiological signals[16]. The entropy calculation for a given time series is as follow.

Assume we have an EEG signal with N-point samples $(u(i): 1 \le i \le N)(u(i): 1 \le i \le N)$. For this time series we do as follow to calculate sample entropy.

(1) Perform phase space reconstruction on u(i) according to the sequence orders. At the end of this step, we obtain a set of m-dimensional vectors $(m \le N-2)$. The reconstructed vector is as Eq.1. in Eq.1 and Eq.2, $i = 1,2,\dots,N-m+1$ and $u_0(i)$ is the average value.

$$X_i^m = \{u(i), u(i+1), \dots, u(i+m-1) - u_0(i)\} \quad (1)$$

$$u_0(i) = \frac{1}{m}\sum_{j=0}^{m-1} u(i+j) \quad (2)$$

(2) Calculate the distance between two vectors X_i^m and X_j^m. The distance is defined as the maximum difference values between the corresponding elements of two vectors.

(3) Define Heaviside function which counts number of distance above threshold value (r) which usually defines as 0.2*std (standard deviation) of given time series.

(4) By defining the function $\emptyset(n,r)\emptyset(n,r)$ as Eq.3 and repeating steps from (1) to (4) a set of (m+1)-dimensional vectors are constructed.

$$\emptyset(n,r) = \frac{1}{N-m}\sum_{i=1}^{N-m}\left[\frac{1}{N-m-1}\sum_{j=1,j\neq i}^{N-m} D_{ij}^m\right] \quad (3)$$

(5) Finally, define Eq.4 and Eq.5 which is sample entropy of given signal.

$$\emptyset^{+1}(n,r) = \frac{1}{N-m}\sum_{i=1}^{N-m}\left[\frac{1}{N-m-1}\sum_{j=1,j\neq i}^{N-m} D_{ij}^{m+1}\right] \quad (4)$$

$$Sample\ entropy(m,n,r) = \lim_{N\to\infty}\left[ln\emptyset^m(n,r) - ln\emptyset^{m+1}(n,r)\right] \quad (5)$$

If the number of given time series samples (N) is limited (like EEG signals), the sample entropy can be defined as $ln\emptyset^m(n,r) - ln\emptyset^{m+1}(n,r)$ $ln\emptyset^m(n,r) - ln\emptyset^{m+1}(n,r)$. for details about sample entropy see[17]. For fuzzy entropy, the approach is the same as sample entropy but with different distance function. In fuzzy entropy we use Eq.6 as a fuzzy distance function instead of Heaviside function in sample entropy. Fuzzy membership function $\mu(D_{ij}^m, n, r)$ $\mu(D_{ij}^m, n, r)$ is an exponential function and in this function, r and n are width and gradient.

$$D_{ij}^m = \mu\left(D_{ij}^m, n, r\right) = \exp\left(\frac{-\left(d_{ij}^m\right)^n}{r}\right) \quad (6)$$

The common value of r is a 0.2 of standard deviation of a signal[18] which we used in both sample and fuzzy entropy.

Feature extraction

Before feature extraction we filtered EEG signals with middle-pass Butterworth filter between 0.5 and 45 Hertz with order of two. In the next step, we extracted sample and fuzzy entropy from all 31 EEG channels for both normal and PTSD subjects with common values (r=0.2*std (EEG) and n=m=2).

To see which EEG channels have the most influences on PTSD disorder and holds more information, we calculate entropy values of all 31 EEG channels with two entropy methods. All signal preprocessing and processing were done in MATLAB software.

Figure.1 illustrates the distribution of sample entropy and fuzzy entropy of six healthy and six PTSD subjects for all 31 EEG channels. Figure 1 shows overall mean value of sample and fuzzy entropy are higher in PTSD group in compare to normal group. This result indicates that in patients with PTSD disorder, the overall entropy value of all EEG channels is higher which means that PTSD disorder can bring irregularity to EEG signals.

Between two entropy methods (sample and fuzzy entropy), sample entropy showed more differences in normal and PTSD group which indicates the superiority of this method in compare to fuzzy entropy.

Fig. 1. Sample entropy and fuzzy entropy distribution of six healthy and six PTSD subjects

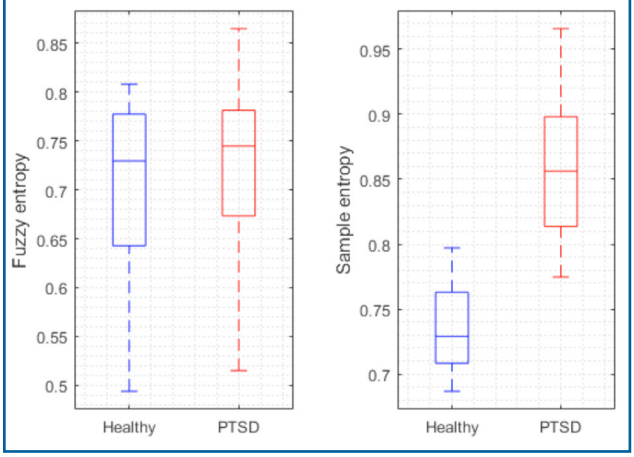

Figure 2 and Figure.3 illustrates the brain map of sample entropy and fuzzy entropy of six healthy subjects and six subjects with PTSD disorders. Entropy values are color coded the way dark red colors indicates higher entropy value and in opposite, dark blue colors indicate smaller entropy values. There are two rows in each figure (Figure 2 and Figure 3), the first row shows brain maps of six healthy subjects (H) and second row shows brain maps of six patients (P) with PTSD disorders. By comparing brain maps of two normal and PTSD groups, we can conclude that channels which are located in frontal lobe of the brain, are the channels with most influences in PTSD disorder. Figure 4 shows the entropy difference between healthy and PTSD groups in all 31 EEG channels. EEG channels which are colored with bright yellow, are the channels with higher entropy differences and channels which are colored with dark blue, are the least important channels with less entropy differences between healthy and PTSD groups. Channels which are located in frontal lobe of the brain showed higher entropy differences between healthy and PTSD groups. This results proves the fact that frontal lobe of the brain plays an important role in emotional experience of a subject[19,20,22]. Among all 31 available EEG channels, FP1, FP2 and FC6 are the channels with higher sample entropy differences and channel FC6 is the channel with higher fuzzy entropy difference between healthy and normal groups[23]. The sample entropy showed entropy differences in three channels (FP1, FP2 and FC6) which are located in frontal and right hemisphere of the brain so in compare to fuzzy entropy, is better tool for PTSD diagnosis problems. In the central part of the brain, the sample and fuzzy entropy had the smallest difference between healthy and PTSD subjects so the channels which are located in this region is not effective for PTSD detection problems.

Fig. 2. Fuzzy entropy brain map of original EEG signals (200 seconds) for healthy subjects (H, first row) and PTSD patients (P, second row)

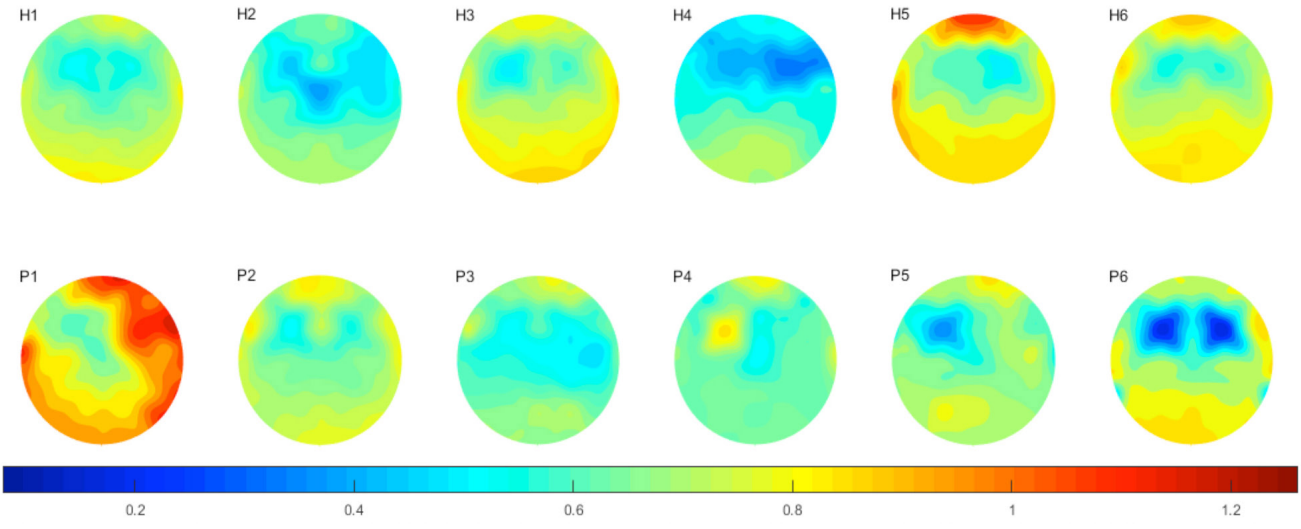

Fig. 3. Sample entropy brain map of original EEG signals (200 seconds) for healthy subjects (H, first row) and PTSD patients (P, second row)

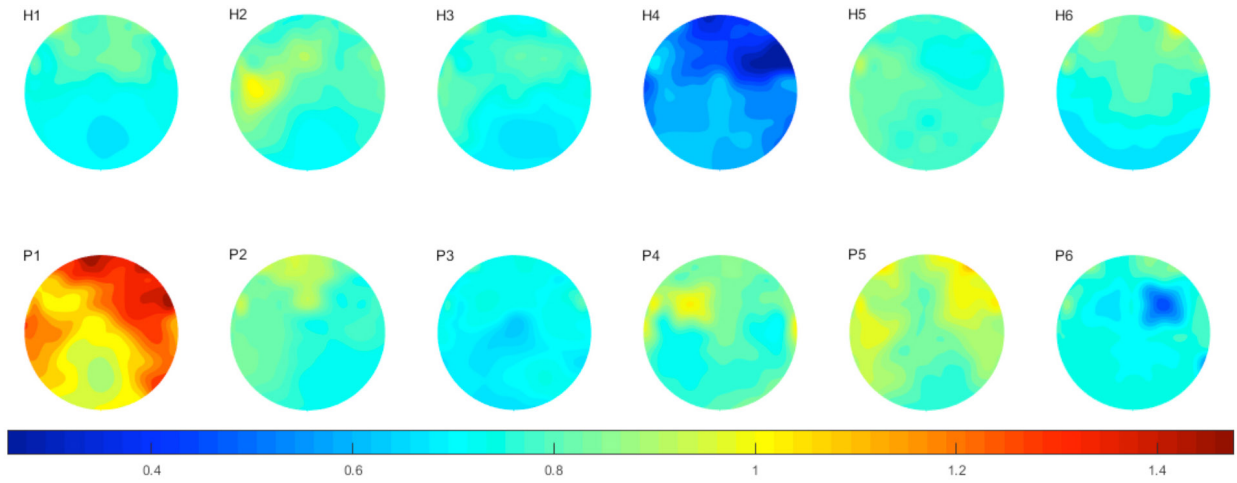

Fig. 2. Fuzzy entropy brain map of original EEG signals (200 seconds) for healthy subjects (H, first row) and PTSD patients (P, second row)

Fig. 3. Sample entropy brain map of original EEG signals (200 seconds) for healthy subjects (H, first row) and PTSD patients (P, second row)

Fig 4. sample entropy and fuzzy entropy differences between healthy and PTSD groups. Yellow color indicates the channels with higher entropy differences.

In Table.1, we reported the mean and standard deviation of sample and fuzzy entropy of six healthy and PTSD subjects for three best channels (FP1, FP2 and FC6) which had the biggest entropy differences based on our previous results. In Table.1, the sample entropy of subjects with PTSD disorder is within 0.91 to 0.94 which is about 0.2 higher in compare to healthy subjects. This results indicates the fact that entropy values and so the EEG signals irregularity of subjects with PTSD disorder is higher in compare to healthy subjects. Also the average Fuzzy entropy of three bets channels (FP1, FP2 and FC6) in PTSD group is slightly higher in compare to healthy group but this difference is not the same as it was for sample entropy which shows the superiority of sample entropy in compare to fuzzy entropy.

Table 1.Average fuzzy and sample entropy of three best EEG channels among six healthy and PTSD groups.

	Healthy			PTSD		
Channels	FP1	FP2	FC6	FP1	FP2	FC6
Average fuzzy entropy	0.78	0.79	0.64	0.81	0.86	0.76
Standard deviation fuzzy entropy	0.19	0.17	0.15	0.12	0.14	0.20
Average sample entropy	0.71	0.72	0.70	0.94	0.96	091
Standard deviation sample entropy	0.18	0.15	0.22	0.27	0.21	0.25

Conclusions

Post thematic stress disorder is a brain disorder which will influence EEG signals. In this paper we investigated the entropy characteristic of EEG signals of patients who suffers from PTSD disorder. Overall results show that average entropy values of whole EEG channels will increase for PTSD groups. This entropy increments are not equal in all EEG channels. Channels FP1, FP2 and FC6 which are located in frontal and right hemisphere of the brain, showed more entropy differences between PTSD and healthy groups. The average entropy values with sample entropy method was higher which means that sample entropy is a better tool for measuring entropy of PTSD EEG signals. We found that the entropy values above certain threshold (about 0.9) can be an index of PTSD in channels FP1, FP2 and FC6.

Conflict of interest: We do not have any conflict of interest

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