ANALYSIS OF SINGING DURING EPILEPTIC SEIZURES BASED ON PARTIAL COHERENCE

R. LE BOUQUIN JEANNÈS(1), G. FAUCON(1), F. BARTOLOMEI(2), P. CHAUVEL(2)

(1) *Laboratoire de Traitement du Signal et de l'Image, INSERM EPI 9934*
Université de Rennes 1, bât. 22, Campus de Beaulieu, 35042 Rennes Cedex, France
(2) *Laboratoire de Neurophysiologie et Neuropsychologie, INSERM EPI 9926*
Faculté de médecine, 27, Bd Jean Moulin, 13385 Marseille Cedex 05, France
e-mail : Regine.Le-Bouquin-Jeannes@univ-rennes1.fr

ABSTRACT

This paper deals with the analysis of singing during epileptic seizures. This phenomenon is rare and seems to appear when the origin of the seizure is in the temporal lobe. Analyzing the relations between signals belonging to different structures may contribute to define the role of each of them and derive a neural network involved during singing production. To study the relations along time, we choose to estimate the coherence function and the partial coherence function. The results obtained show that some coherences increase during singing phenomenon, and differences appear between given coherences and the same coherences conditioned on a third signal. This last result informs us of the contribution of a signal in the relation between two others.

1. INTRODUCTION

Our concern is the analysis of singing which may occur during an epileptic seizure. This phenomenon is rare and only a few studies are carried out on this automatism. It seems that this phenomenon appears only when the origin of the seizure is the temporal lobe [1] and never in frontal lobe epilepsies [2]. Different papers have described several types of singing during seizures [3,4,5,6] and some of them lead to wonder about the role of frontal structure in the genesis of singing [5]. Since the role of temporal structures and right frontal lobe in the music perception is well known, it may be interesting to look for their contribution in the singing. This study was carried out on patients for whom singing appears during epileptic seizures. These patients had drug-resistant temporal lobe epilepsy and therefore a presurgical exploration was planned. Intracerebral electrodes are stereotaxically implanted in cortex in order to determine the structures involved in seizures and the accurate limits of a future cortical excision [7]. So, we can analyze the electrical activity recorded from these electrodes and it seems relevant to study the relations between recorded signals. We propose to analyze the coherence function between two signals belonging to different structures and the partial coherence function. Analyzing these relations may contribute to define the role of each of them and derive a singing network.
After a presentation of the coherence functions we use, we present our approach and results, before drawing some conclusions and perspectives.

2. BASIC TOOLS

First of all, in order to determine the linear relation between two signals, we compute, at each frequency f_j, the ordinary coherence function [8]. We recall the definition of the complex ordinary coherence function computed from two observations x and y assumed to be stationary:

$$\rho_{xy}(f_j) = \frac{\gamma_{xy}(f_j)}{\gamma_{xx}^{1/2}(f_j)\gamma_{yy}^{1/2}(f_j)} \qquad (1)$$

where $\gamma_{xy}(f_j)$ is the cross power spectral density (cross psd) between x and y, $\gamma_{xx}(f_j)$ and $\gamma_{yy}(f_j)$ are respectively the psd of x and y, j is the frequency bin index.
This measure varies in module between 0 and 1 and it is representative of the correlated components present in the two quantities x and y.
Secondly, to evaluate the contribution of a third signal z on the two others x and y, we consider the partial coherence between x and y conditioned on this signal z, named $\rho_{xy/z}(f_j)$ [8]. This coherence allows to determine the contribution of a structure in the relation between the two others.
This coherence may be rewritten from the coherence function computed from each pair of signals, as follows:

$$\rho_{xy/z}(f_j)=\frac{\rho_{xy}(f_j)-\rho_{xz}(f_j)\rho_{zy}(f_j)}{\sqrt{1-|\rho_{xz}(f_j)|^2}\sqrt{1-|\rho_{yz}(f_j)|^2}} \qquad (2)$$

This partial coherence corresponds to the ordinary coherence between x and y when the correlated components of x and y with z are removed. If the signal z contributes largely in the two observations, the partial coherence $\rho_{xy/z}(f_j)$ falls down to 0.

3. METHOD

3.1. Approach proposal

Stereoelectroencephalographic (SEEG) signals are not stationary and the coherences have to be computed on a finite length. Power spectral densities are estimated on K blocks by Fast Fourier Transform (256-point FFT) using a rectangular window and a 50% overlap:

$$\hat{\gamma}_{uv}(f_j,k)=\frac{1}{K}\sum_{l=k-K+1}^{k}U(f_j,l)V^*(f_j,l) \qquad (3)$$

where $U(f_j,l)$ and $V(f_j,l)$ represent the Fourier transforms (256-point FFT) of the two signals u and v on the block l, k is the current block number and K is the number of blocks on which the estimation is performed ($K=19$ which corresponds to 10 adjacent blocks). According to equations (1) and (2), we estimate the ordinary coherence and the associated partial coherence on each block k (respectively $\hat{\rho}_{xy}(f_j,k)$ and $\hat{\rho}_{xy/z}(f_j,k)$). Since SEEG signals are recorded from depth electrodes at a sampling rate of 200 Hz, the coherence functions are estimated every 0.64 s on a 12.8 s window.

Simulations show that the bias of the coherence (ordinary or partial) magnitude depends only of its magnitude, for a given set of parameters (estimation length, overlap) [9,10]. For low values of coherence, this bias may be important and a correcting algorithm based on the knowledge of the bias versus the coherence magnitude and presented in [9] is introduced to reduce this bias. For each estimated coherence magnitude at a given frequency, we subtract an estimate of the bias derived from a table giving the correspondence between the theoretical coherence and the bias. The ordinary and partial coherence magnitudes after correction are respectively called $\left|\hat{\rho}^{c}_{xy}(f_j,k)\right|$ and $\left|\hat{\rho}^{c}_{xy/z}(f_j,k)\right|$. Then, we compute, on each block k, the following averaged quantities [9]:

$$\bar{\rho}_{xy}(k)=\frac{1}{card(F)}\sum_{f_j\in F}\left|\hat{\rho}^{c}_{xy}(f_j,k)\right|, \qquad (4)$$

$$\bar{\rho}_{xy/z}(k)=\frac{1}{card(F)}\sum_{f_j\in F}\left|\hat{\rho}^{c}_{xy/z}(f_j,k)\right|, \qquad (5)$$

where F is a set of frequencies.

The averaging (in the frequency domain) allows an easier interpretation of the degree of coherence and reduces the variance of the estimators.

3.2. Discussion on the averaging

A major problem is the definition of the set of frequencies on which the averaging is performed. On the one hand, if we consider all frequencies in the averaging, the variance of the coherence estimator is reduced but the smoothing may be too large and hide some significant changes. On the other hand, if the averaging is performed only on few frequencies, the variance is increased and the averaged coherence is difficult to interpret. A good compromise is to consider 32 frequency bins to get an acceptable variance. This last one depends on the real values of the coherence at retained frequencies. With the set of parameters we choose, the variance attains its maximum for a theoretical coherence equal to 0.4 in module, whatever the frequency is. By considering the worst case and using an averaging over 32 frequencies, the maximum variance of the averaged coherence is around 1e-3. A first choice consists in taking the 32 lowest frequency bins which correspond generally to high energies. A second approach is to choose a criterion *a priori*; the one we selected consists in extracting the 32 frequencies giving the highest ordinary coherence magnitudes. Then, we average these highest ordinary coherence magnitudes and the "corresponding" partial coherences over the same frequencies.

4. RESULTS

This study was performed on three patients having a singing during seizures. SEEG recordings demonstrated the origin of seizures in the temporal lobe for the three patients. The seizure initiated in medial temporal structures (amygdala and hippocampus) and the anterior neocortex (anterior and mid part of the middle temporal gyrus). The occurrence of singing was delayed, and occurred just after the appearance of a rhythmic discharge over the first temporal gyrus in its more lateral part (corresponding to the auditory associative areas).

We present the results obtained on a given patient. We have analyzed the averaged (partial and ordinary) coherences between different structures of the right hemisphere such as the prefrontal lobe (F), the inferior parietal region (P), the first temporal gyrus (T1), the temporal anterior neocortex (T2), the hippocampus (H) and the amygdala (A). In a first step, the coherences are obtained with an averaging on the 32 lowest frequencies. Singing phenomenon is characterized by a significant increase of the averaged ordinary coherence between T1 and F, $\overline{\rho}_{T_1F}$, and at a lower degree, by an increase of the coherence between T1 and P, $\overline{\rho}_{T_1P}$, and the coherence between F and P, $\overline{\rho}_{FP}$. The averaged partial coherence between T1 and F conditioned on P, $\overline{\rho}_{T_1F/P}$, is comparable to the corresponding ordinary coherence $\overline{\rho}_{T_1F}$ while the partial coherences $\overline{\rho}_{FP/T_1}$ and $\overline{\rho}_{T_1P/F}$ remain quite constant with regard to the corresponding ordinary coherences $\overline{\rho}_{FP}$ and $\overline{\rho}_{T_1P}$ respectively.

In a second step, when we consider the averaging on the 32 frequencies giving the highest ordinary coherences, the previous result becomes evident. Figure 1 displays the most pertinent results, the singing phenomenon appears around $120\ \text{s}$ and lasts $20\ \text{s}$. As previously the ordinary coherences $\overline{\rho}_{T_1F}$, $\overline{\rho}_{T_1P}$ and $\overline{\rho}_{FP}$ increase when singing occurs while the partial coherences $\overline{\rho}_{T_1P/F}$ and $\overline{\rho}_{FP/T_1}$ remain at the same level as before singing. The partial coherences between T1 and F, conditioned either on P or H, $\overline{\rho}_{T_1F/P}$ and $\overline{\rho}_{T_1F/H}$, are practically equal to the ordinary coherence $\overline{\rho}_{T_1F}$. We can note also a slight increase of $\overline{\rho}_{HF}$, $\overline{\rho}_{T_1H}$ during the singing phenomenon with values of the partial coherences $\overline{\rho}_{HF/P}$, $\overline{\rho}_{HF/T_1}$, $\overline{\rho}_{T_1H/F}$ slightly lower than the corresponding coherences.

These results have been confirmed on another seizure of the same patient. Two other patients are now under study. Even if their epileptic network is more complex, it seems that the prefrontal lobe and the auditory associative areas take part in the singing automatism.

5. CONCLUSION

We proposed to analyze relations between structures during singing phenomenon thanks to the averaged coherence functions. Our data underline the major role of the synchronization between prefrontal and auditory cortices in determining the occurrence of singing in seizures. We pointed out the importance of the choice of the set of frequencies used in the averaging, the results being more pertinent when we average the highest ordinary coherences and the corresponding partial coherences.

6. PERSPECTIVES

Now, we plan to investigate the partial coherence conditioned on the signals issued respectively from the prefrontal lobe and the auditory associative areas to precise the exact role of these two structures in the singing phenomenon [8]. The second point is to compute the coherence from eigenspectra using spheroidal functions instead of computing power spectral densities by Fast Fourier Transforms [11].

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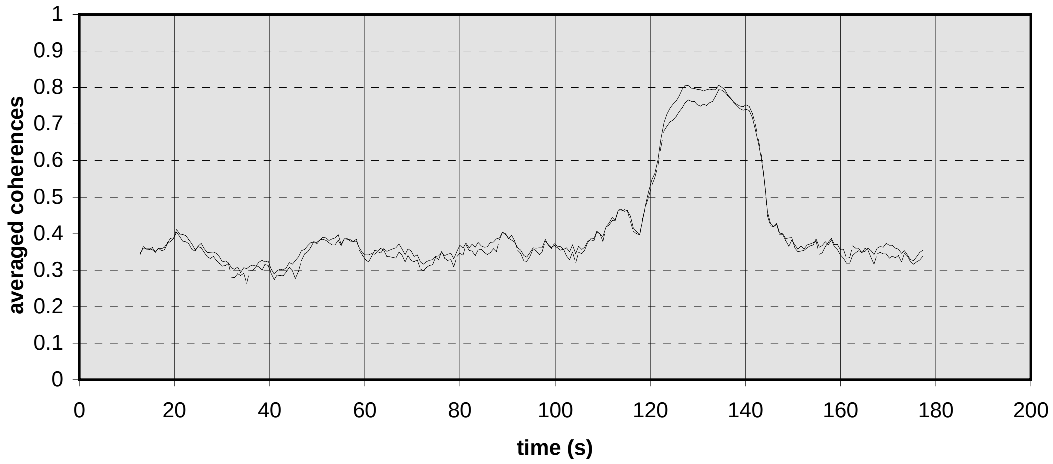
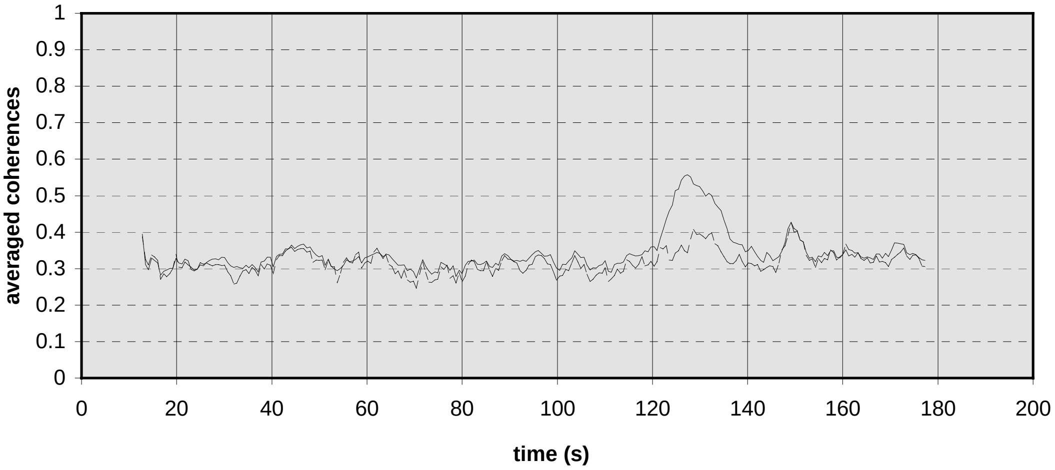


(a)



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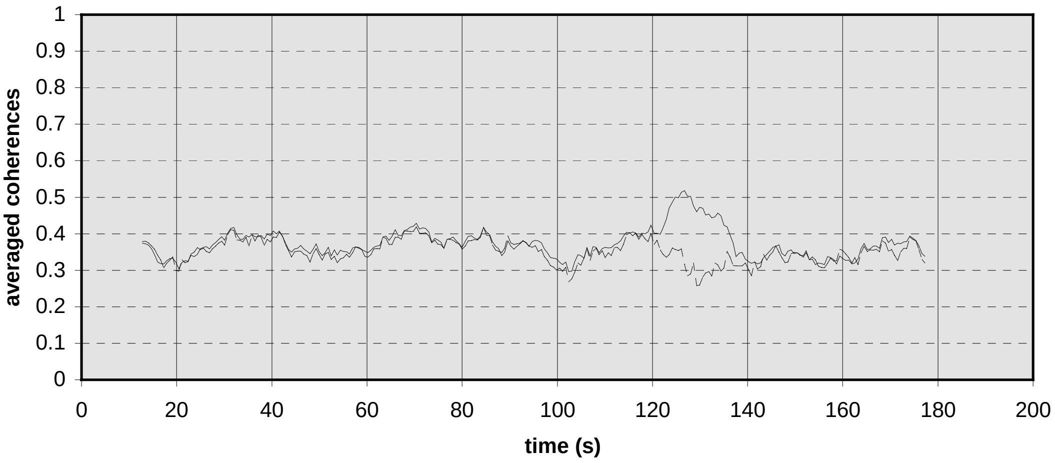

(c)

Figure 1. Ordinary coherences (continuous lines) and partial coherences (dotted lines)
(a) T1 - F, (b) F - P, (c) T1 - P