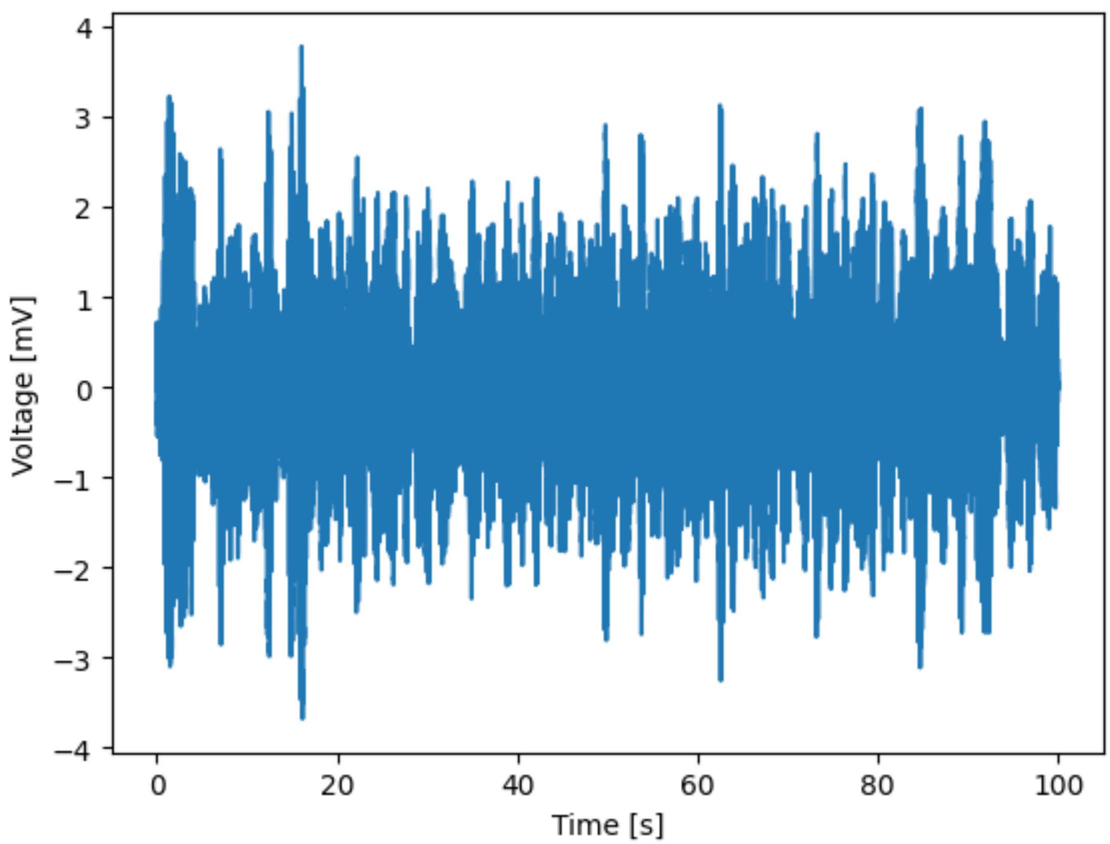
1.) LFP-2.mat

```
In [ ]: from scipy.io import loadmat
        import matplotlib.pyplot as plt
        import numpy as np
        from scipy.signal import spectrogram
        from scipy import signal
        import random as rand
```

```
In [ ]: # Load the data.
        lfp2 = loadmat('LFP-2.mat')          # Load the data,
        t = lfp2['t'][0]                     # ... extract t, the time variable,
        LFP = lfp2['LFP'][0]                 # ... and LFP, the voltage variable.
        dt = t[1] - t[0]                     # Define the sampling interval,
        fNQ = 1 / dt / 2                     # ... and Nyquist frequency.
```

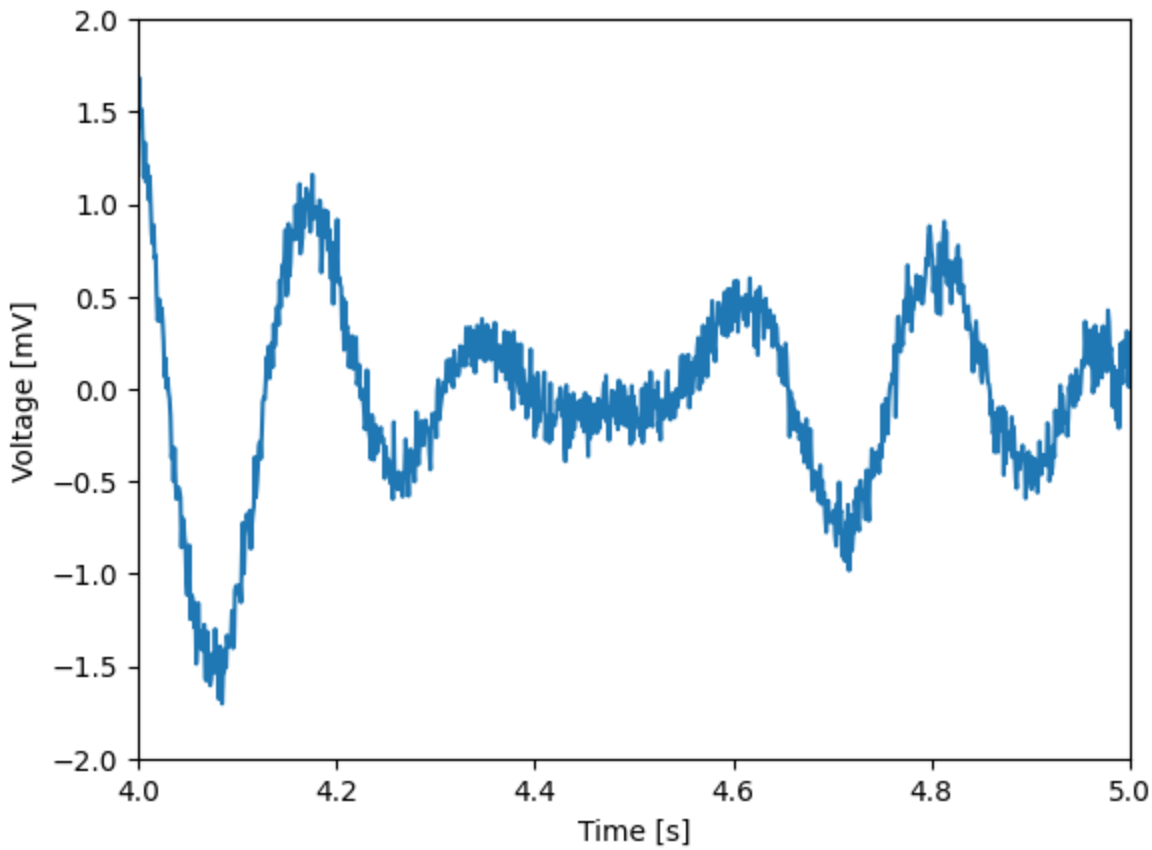
i. Visualize the time series data. What rhythms do you observe? Do you detect evidence for CFC in your visualizations?

```
In [ ]: plt.plot(t,LFP)
        plt.xlabel('Time [s]')       # ... with axes labeled.
        plt.ylabel('Voltage [mV]');
```




```
In [ ]: #zoom in on 1 second of activity
        plt.plot(t,LFP)
        plt.xlim([4,5])
        plt.ylim([-2, 2])
```

```
plt.xlabel('Time [s]')        # ... with axes labeled.
plt.ylabel('Voltage [mV]');
plt.show()
```



a dominant low-frequency rhythm - not really seeing any evidence of CFC so far

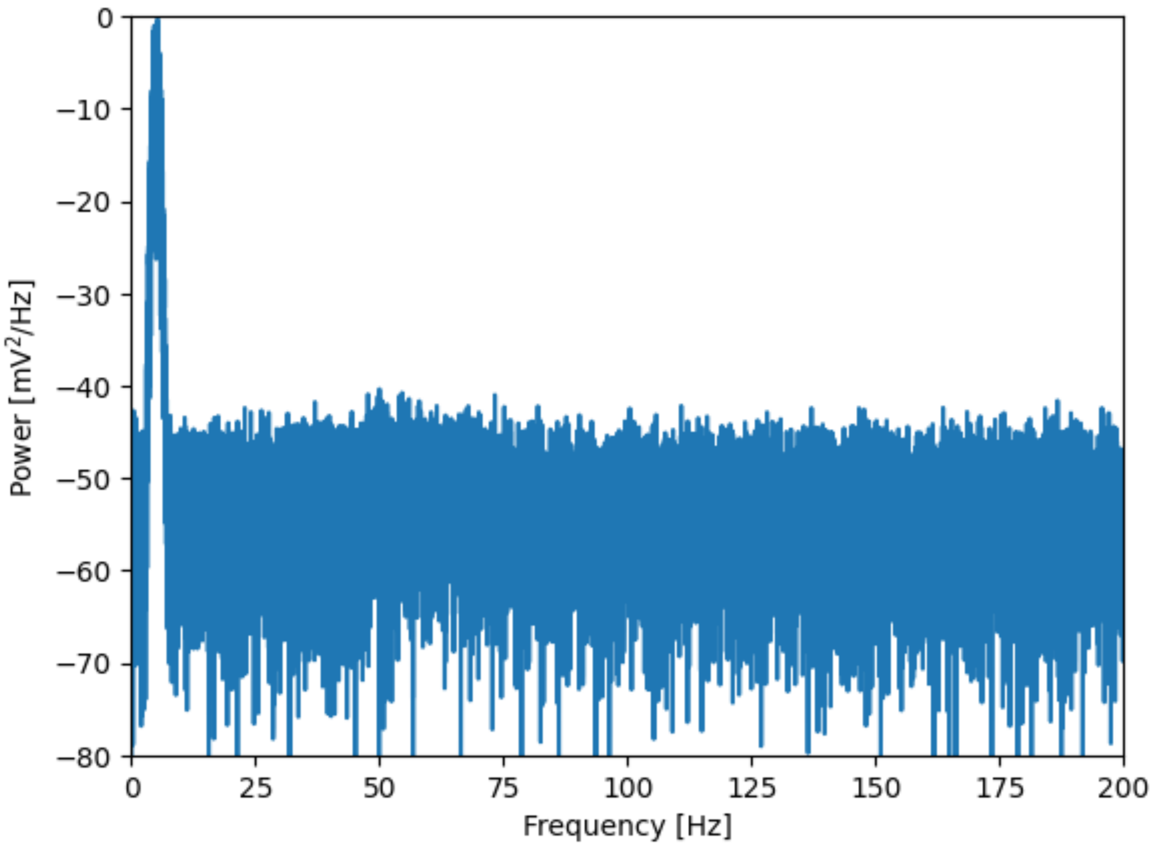
ii.) Plot the spectrum vs the frequency for this data

In [ ]:
```
dt = t[1] - t[0]                 # Define the sampling interval,
T = t[-1]                        # ... the duration of the data,
N = len(LFP)                     # ... and the no. of data points

x = np.hanning(N) * LFP             # Multiply data by a Hanning taper
xf = np.fft.rfft(x - x.mean())          # Compute Fourier transform
Sxx = 2*dt**2/T * (xf*np.conj(xf)) # Compute the spectrum
Sxx = np.real(Sxx)                  # Ignore complex components

df = 1 / T                       # Define frequency resolution,
fNQ = 1 / dt / 2                 # ... and Nyquist frequency.

faxis = np.arange(0, fNQ + df, df) # Construct freq. axis
plt.plot(faxis, 10 * np.log10(Sxx))     # Plot spectrum vs freq.
plt.xlim([0, 200])                     # Set freq. range,
plt.ylim([-80, 0])                     # ... andplt. decibel range
plt.xlabel('Frequency [Hz]')           # Label the axes
plt.ylabel('Power [mV$^2$/Hz]');
```



This highlights a low-frequency peak around 5ish Hz that is also the largest - this corresponds to the dominanting slow rhythmn we saw last.

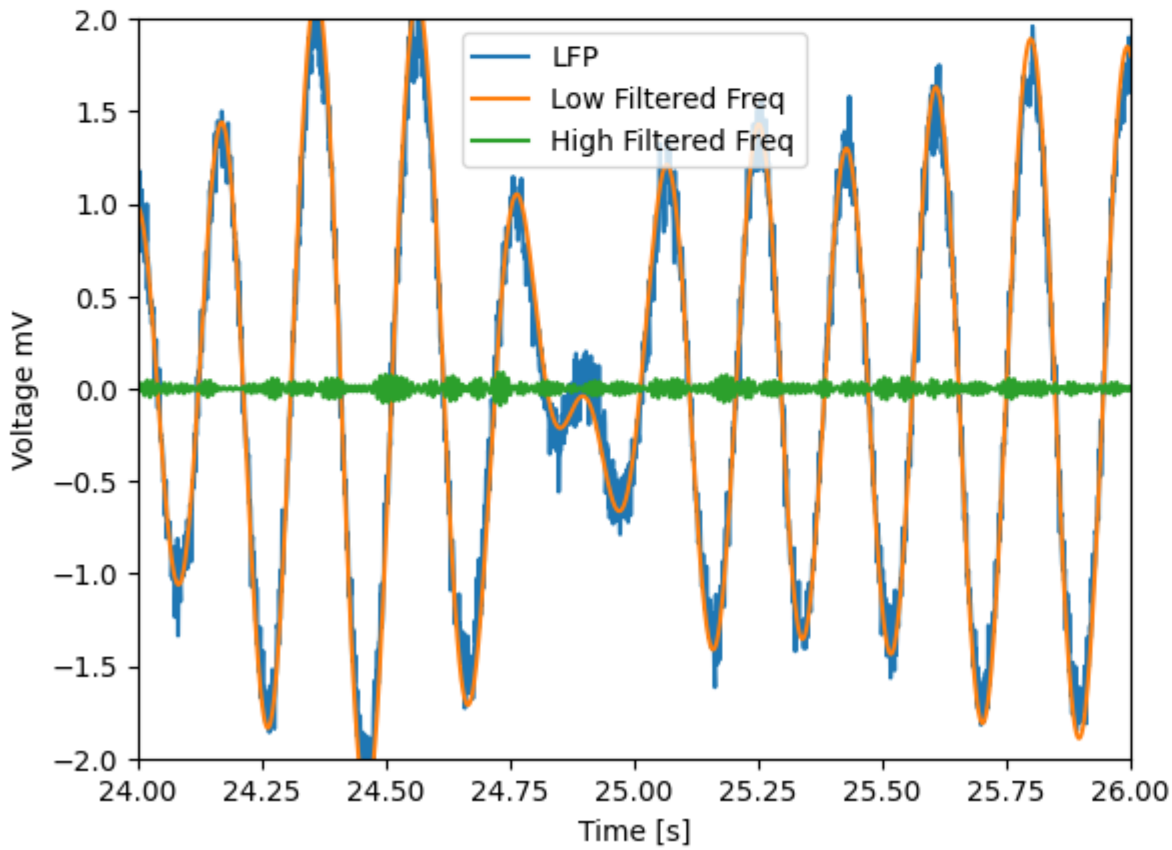
iii.) APPLY the CFC method. What choices will you make, and why? What if any CFC do you find?

In [ ]:
```
# Low frequency band. (the dominant)
Wn = [5,7];                          # Set the passband for low frequency band
n = 100;                               # ... and filter order,
                                       # ... build the bandpass filter,
b = signal.firwin(n, Wn, nyq=fNQ, pass_zero=False, window='hamming');
Vlo = signal.filtfilt(b, 1, LFP);   # ... and apply it to the data.

# High frequency band.
Wn = [75, 120];                         # Set the passband for high frequency band (bu
n = 100;                               # ... and filter order,
                                       # ... build the bandpass filter,
b = signal.firwin(n, Wn, nyq=fNQ, pass_zero=False, window='hamming');
Vhi = signal.filtfilt(b, 1, LFP);   # ... and apply it to the data.
```

In [ ]:
```
plt.plot(t, LFP)
plt.plot(t, Vlo) #plot the low peak
plt.plot(t, Vhi) #plot the high freq peak
plt.xlabel('Time [s]')
plt.ylabel('Voltage mV')
plt.xlim([24, 26]); #zoom in a specific time interval to get a more detailed graph,
plt.ylim([-2,2]);
plt.legend(['LFP', 'Low Filtered Freq', "High Filtered Freq"])
```

```
plt.show()
```



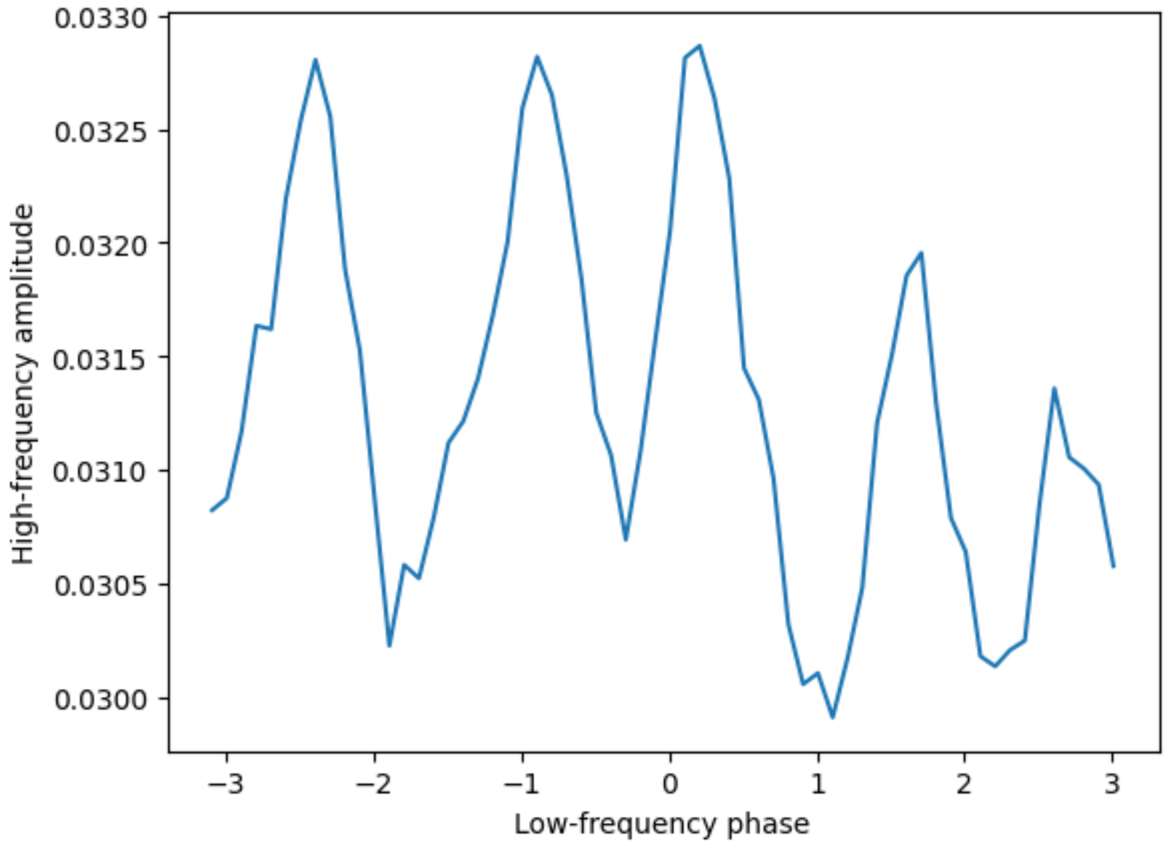
In [ ]:

```
phi = np.angle(signal.hilbert(Vlo))  # Compute phase of low-freq signal
amp = abs(signal.hilbert(Vhi))       # Compute amplitude of high-freq signal
```

In [ ]:

```
p_bins = np.arange(-np.pi, np.pi, 0.1)
a_mean = np.zeros(np.size(p_bins)-1)
p_mean = np.zeros(np.size(p_bins)-1)
for k in range(np.size(p_bins)-1):     #For each phase bin,
    pL = p_bins[k]                     #... lower phase limit,
    pR = p_bins[k+1]                   #... upper phase limit.
    indices=(phi>=pL) & (phi<pR)       #Find phases falling in bin,
    a_mean[k] = np.mean(amp[indices])  #... compute mean amplitude,
    p_mean[k] = np.mean([pL, pR])      #... save center phase.

plt.plot(p_mean, a_mean)                #Plot the phase versus amplitude,
plt.ylabel('High-frequency amplitude')  #... with axes labeled.
plt.xlabel('Low-frequency phase');
```



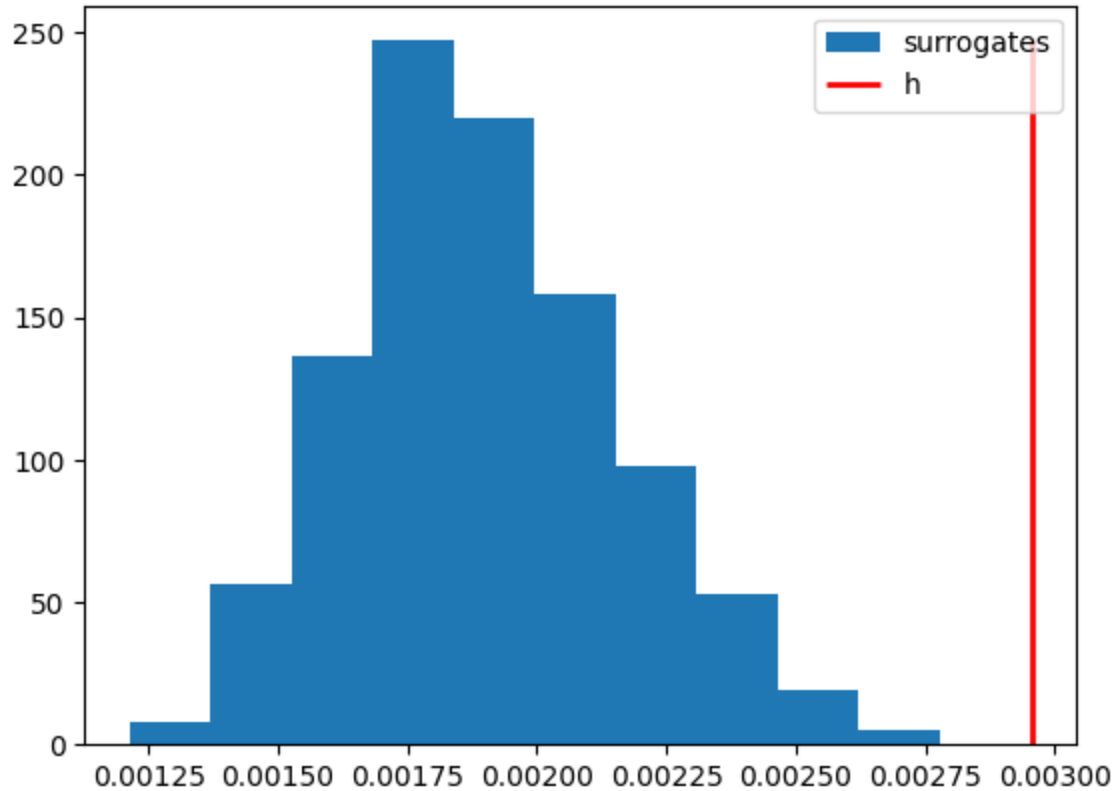
This doesn't seem to suggest a CFC

In [ ]:
```
h = max(a_mean)-min(a_mean)
print(h)
```

0.0029541809184905933

In [ ]:
```
n_surrogates = 1000;                        #Define no. of surrogates.
hS = np.zeros(n_surrogates)                    #Vector to hold h results.
for ns in range(n_surrogates):              #For each surrogate,
    ampS = amp[np.random.randint(0,N,N)]              #Resample amplitude,
    p_bins = np.arange(-np.pi, np.pi, 0.1)          #Define the phase bins
    a_mean = np.zeros(np.size(p_bins)-1)       #Vector for average amps.
    p_mean = np.zeros(np.size(p_bins)-1)       #Vector for phase bins.
    for k in range(np.size(p_bins)-1):
        pL = p_bins[k]                      #... lower phase limit,
        pR = p_bins[k+1]                    #... upper phase limit.
        indices=(phi>=pL) & (phi<pR)        #Find phases falling in bin,
        a_mean[k] = np.mean(ampS[indices]) #... compute mean amplitude,
        p_mean[k] = np.mean([pL, pR])          #... save center phase.
    hS[ns] = max(a_mean)-min(a_mean)        # Store surrogate h.
```

In [ ]:
```
counts, _, _ = plt.hist(hS, label='surrogates')                 # Plot the histogram
plt.vlines(h, 0, max(counts), colors='red', label='h', lw=2)  # Plot the observed h
plt.legend();                                                   # ... include a legen
```



In [ ]:
```
p = sum([s > h for s in hS]) / len(hS) #what is the proportion of surrogante h valu
print(p)
```

```
0.0
```

We reject the null hypothesis of no CFC between the phase of the 5-7 Hz low-frequency band and the amplitude of the 80-120 Hz high frequency band.