

In The Name Of God

HW04

Advanced Neuroscience

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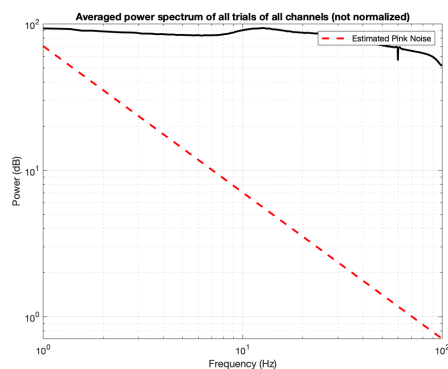
It is noteworthy to mention that I have only used the trials which were marked as clean trials.

■ LFP analysis

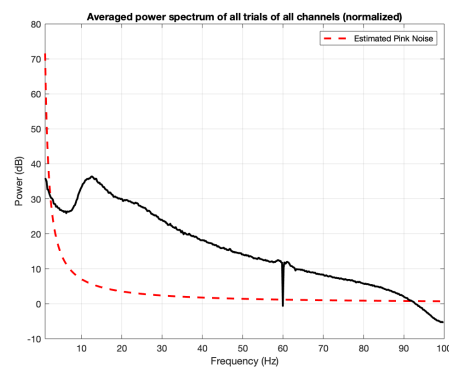
□ Part a - Removing Pink Noise

Pink Noise

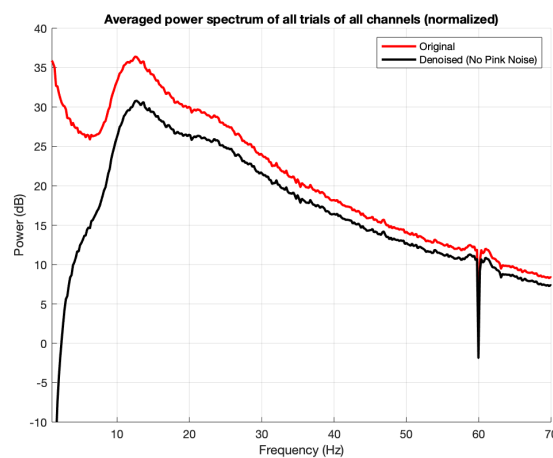
Pink noise or $\frac{1}{f}$ noise is a signal with a frequency spectrum such that the power spectral density is inversely proportional to the frequency of the signal. In order to remove pink noise, I fitted a line with a slope equal to -1 to log-log FFT of the signal and then subtracted this line from the FFT. You can see the fitted line and original and denoised power spectrums of the signal in the figure 1.



(a) Averaged Power Spectrum (Log-Log)



(b) Averaged Power Spectrum



(c) Original and Denoised Power Spectrum

Figure 1: Pink noise, Original Power Spectrum, and Denoised Power Spectrum

As can be seen in Figure 1, the dominant frequency is in the 10 – 15Hz frequency band.

□ Part b - Dominant Frequency

To cluster the electrodes based on their dominant frequency, I calculated the FFT of each trial of channels and then plotted the average power spectrum of trials of each channel in Figure 2.

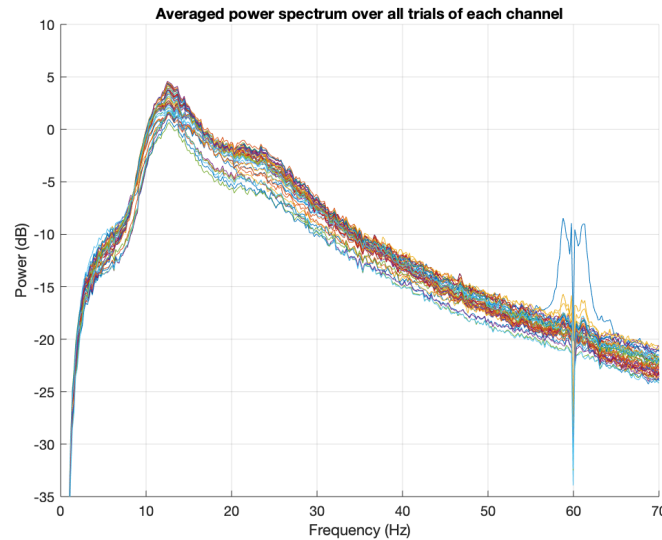


Figure 2: Average Power Spectrum of each Channel

As can be seen in Figure 2, the dominant frequency of all the channels is between 10 – 15Hz.

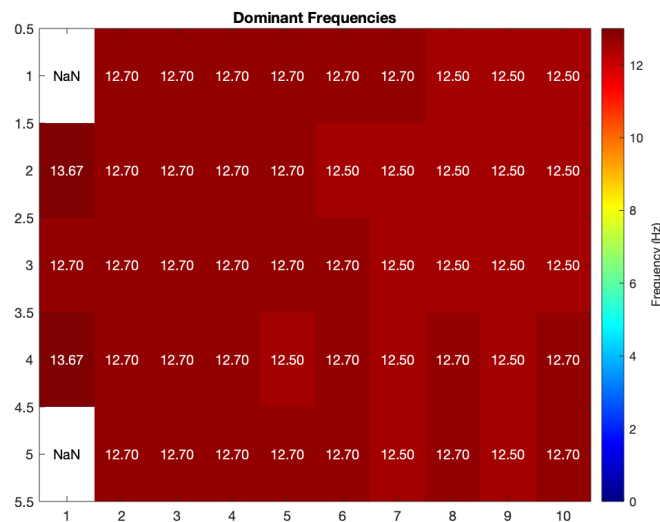


Figure 3: Dominant Frequency of each Channel

As mentioned in the last part, the dominant frequency of all of the channels is about 12.5Hz which is in 10–15Hz frequency band.

□ Part c - Time-Frequency Analysis

Removing Pink Noise

STFT

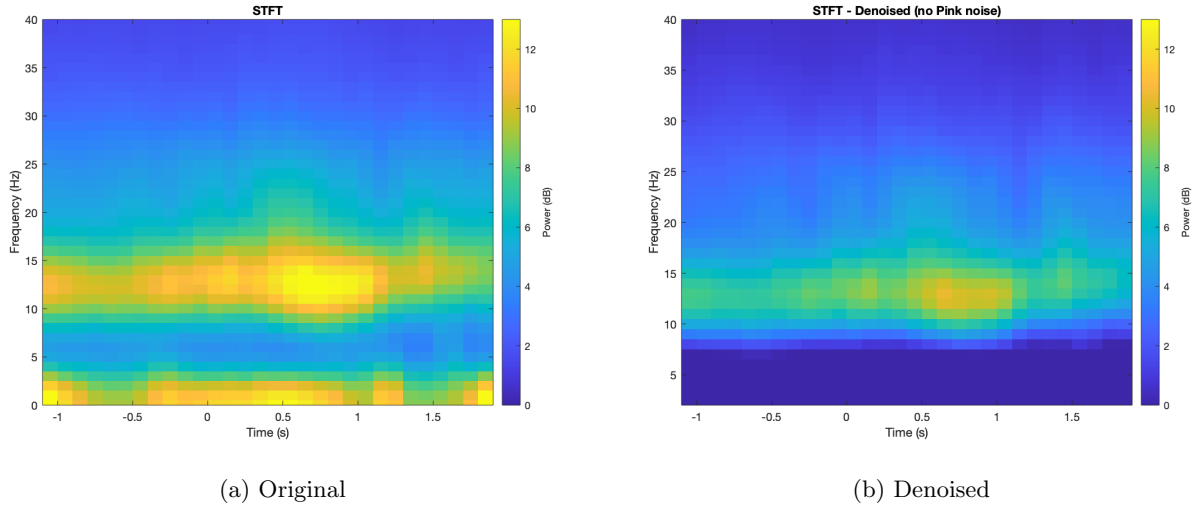


Figure 4: Average Power Spectrum over Time of all Trials of all Channels - STFT

Table 1: Parameters of STFT

Window type	kaiser
Window gain	5
Window size	300ms
Overlap length	200ms
FFT Length	200

Parameters that were used to obtain the STFT of the signal are written down in Table 1. While using smaller window sizes gives better time resolution, low-frequency components would be missed. so I chose these parameters.

Welch

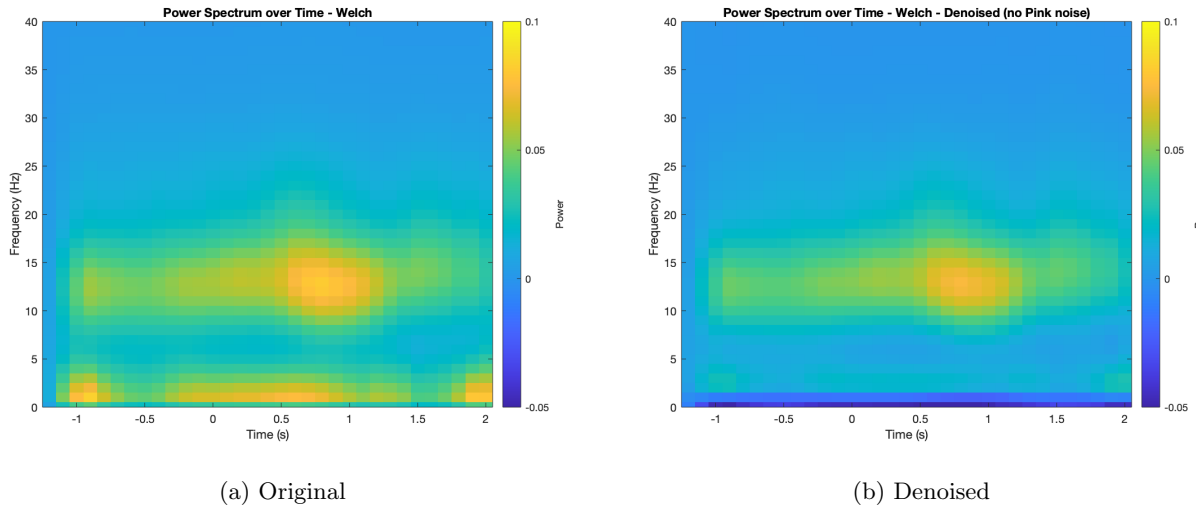


Figure 5: Average Power Spectrum over Time of all Trials of all Channels - Welch

Table 2: Parameters of PWelch

Window size	200ms
Overlap length	100ms
FFT Length	200

As can be seen in the Figures 4 and 5, after 500ms of the onset there is an increase in the power of 10 – 15Hz frequency band.

Wavelet

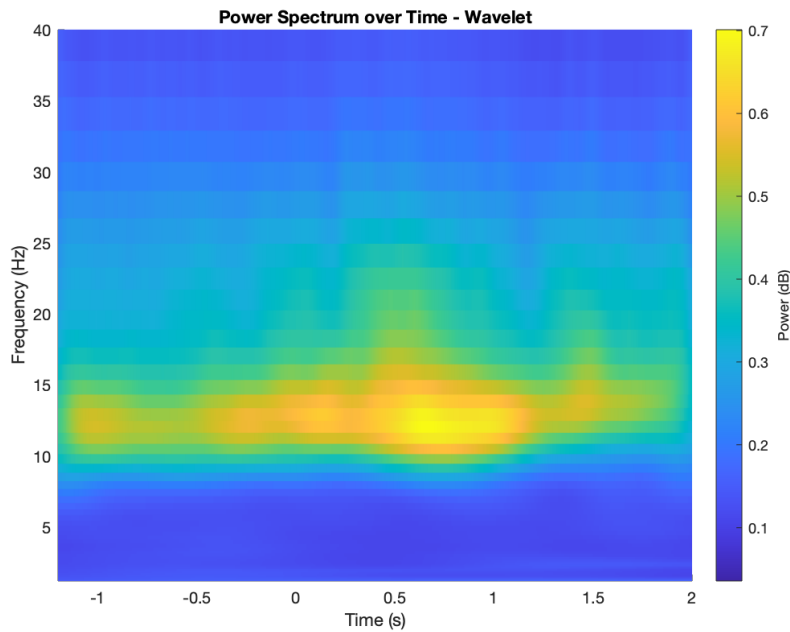


Figure 6: Average Power Spectrum over Time of all Trials of all Channels - Wavelet

□ Part d - Comparing the Results with Hatsopoulos et.al 2006

Beta frequency band shows stronger power compared to the other frequency bands (Figures 2, 4, 5, and 6). I have plotted Fig. 1d of the paper which is average wavelet spectrogram of the signals and my average wavelet power spectrum in Figure 7.

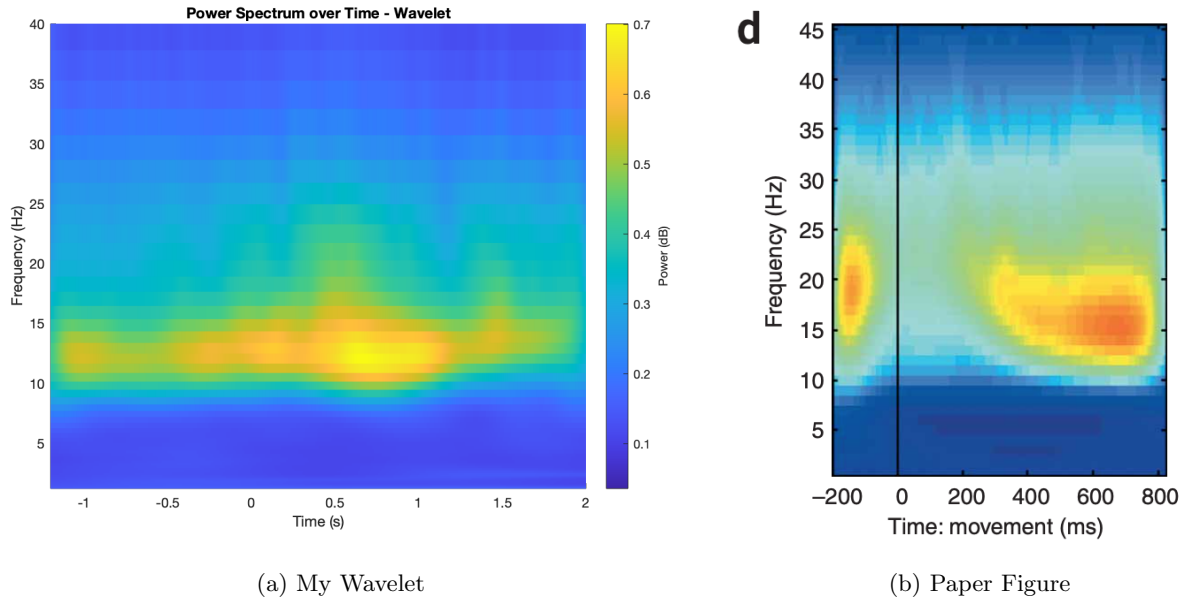


Figure 7: Average Power Spectrum over Time of all Trials of all Channels - Wavelet

As can be seen in both of the plots of Figure 7, there is an increase in the power of 10 – 20Hz frequency band after 500ms of onset. So, the obtained results are similar to the results of Hatsopoulos et.al 2006.

■ Phase propagation (Traveling waves)

□ Part a - Bandpass filtering the recorded signals

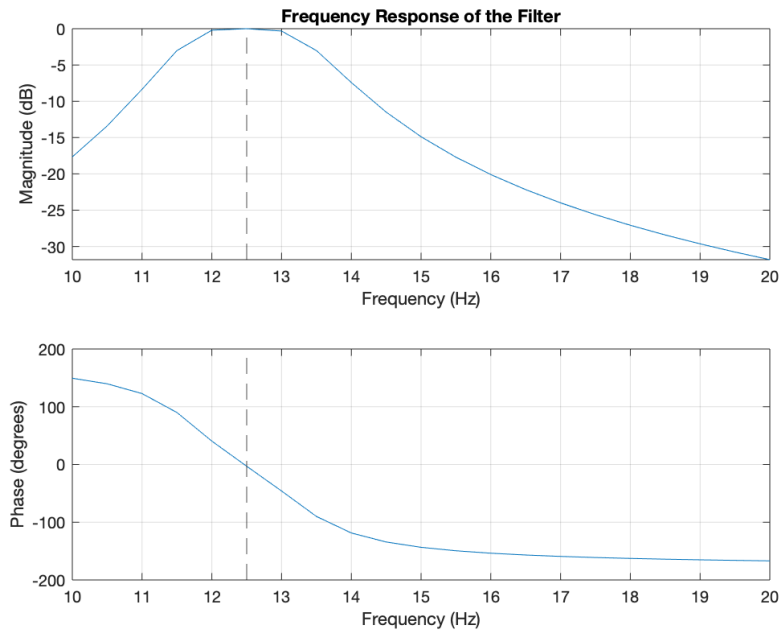


Figure 8: Frequency response of the filter (12 – 13Hz)

I have bandpass filtered the recorded signals using 2^{nd} order Butterworth filter. The most important property of this signal is that its phase is linear over the specified frequency. Figure 15 shows this property very well.

□ Part b - Calculating instantaneous phase

I have calculated the instantaneous phase using the following formula:

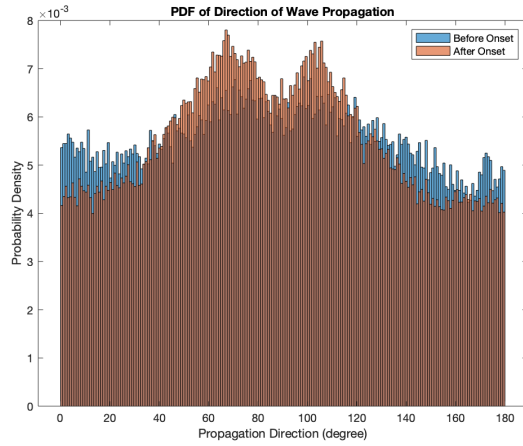
$$\phi(t) = \angle(\text{Hilbert}(x(t)))$$

□ Part c - Wave Demo

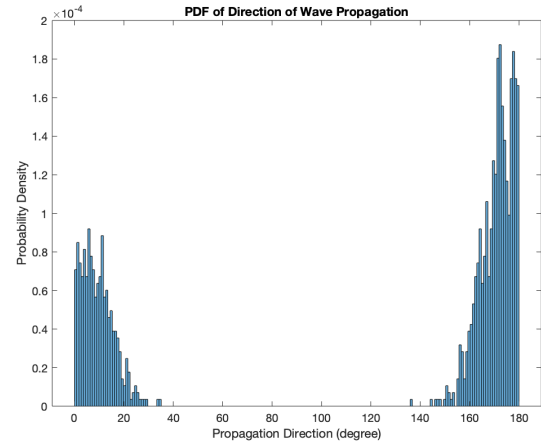
I have observed a wave propagating from right to left in most of the trials.

* Parameters are calculated from $\phi(t)$.

□ Parts d and e - Calculating Wave Metrics



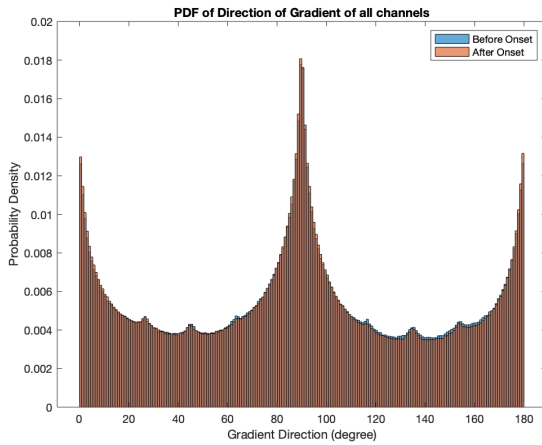
(a) All times



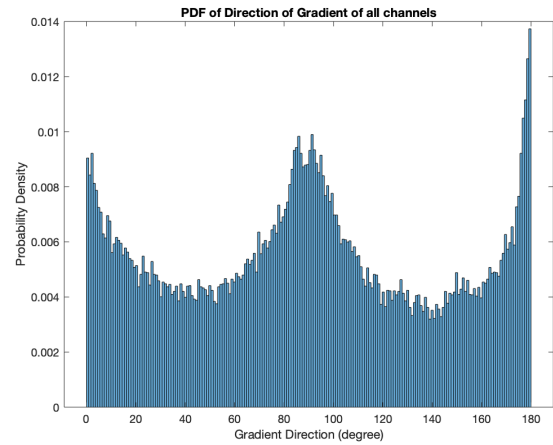
(b) Times with $PGD > 0.5$

Figure 9: Direction of wave propagation (all trials)

As can be seen in Figure 9, PDF of the direction of wave propagation for the times with $PGD > 0.5$ has peaks about 0 and 180 degrees which validate that wave propagates from right to left as same as I observed in the demo. There is a peak of about 0 degrees because when the wave is propagating from right to left, the gradients on the left side of the wave peak have a direction degree close to 180 and the gradient of the right side of the wave peak has a direction degree close to 0.



(a) All times



(b) Times with $PGD > 0.5$

Figure 10: Direction of gradients (all trials of all channels)

As can be seen in Figure 10, the PDF of the direction of gradients has peaked at about 0, 90, and 180 degrees. The reasons for the peaks at 0 and 180 degrees are explained in the last part and there is a peak of about 90 degrees because the electrodes in the first and last rows of the array can only have gradient directions close to -90 and 90 degrees.

□ Part f - Designing a test for validating propagation direction significance

As can be seen in Figure 9 b, the direction of wave propagation during the times with $PGD > 0.5$ is mostly 0 and 180 degrees. To validate this observation, I have validated the null hypothesis that the following distribution comes from a population with a mean equal to zero.

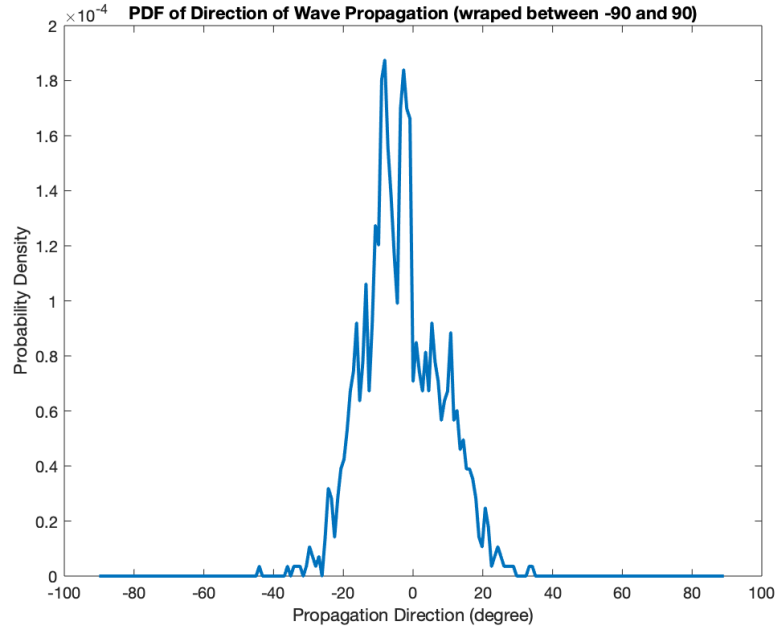


Figure 11: PDF of Direction of Wave Propagation - directions bigger than 90 degrees are subtracted from 180

T-Test validates the null hypothesis with probability equal to 0.9.

□ Part g - Comparing wave speed with criteria's in Sejnowski et.al 2018

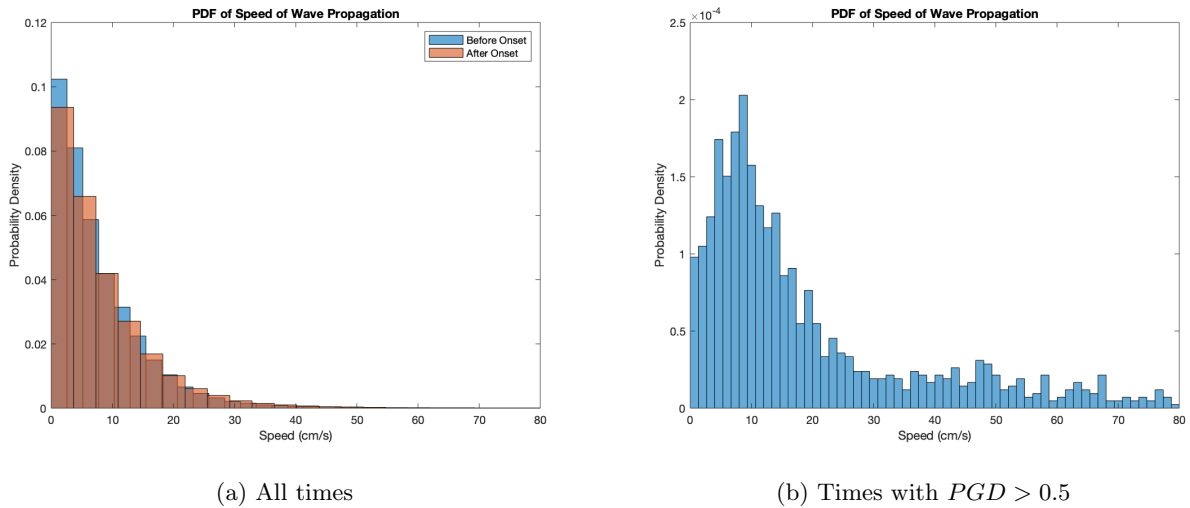
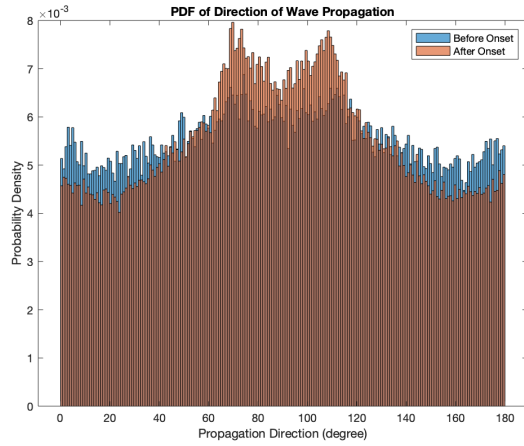


Figure 12: Direction of gradient of all channels

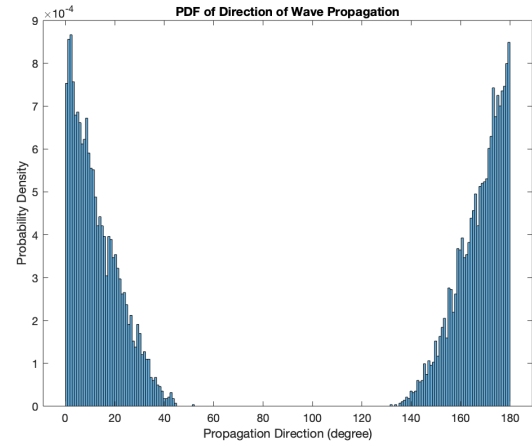
As can be seen in Figure 12, the wave speed is about 0 – 0.8 m/s which is mostly close to what Sejnowski has mentioned in his paper.

* Parameters are calculated from $\cos(\phi(t))$.

□ Parts d and e - Calculating Wave Metrics



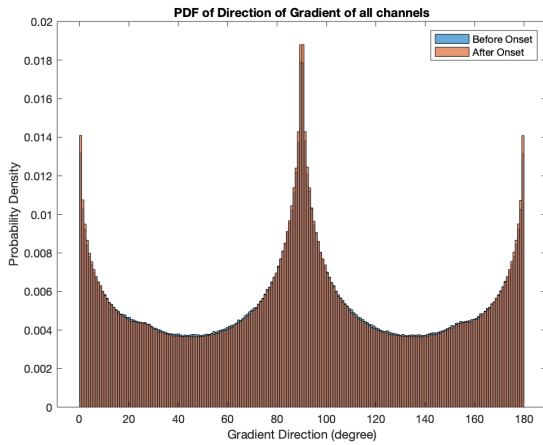
(a) All times



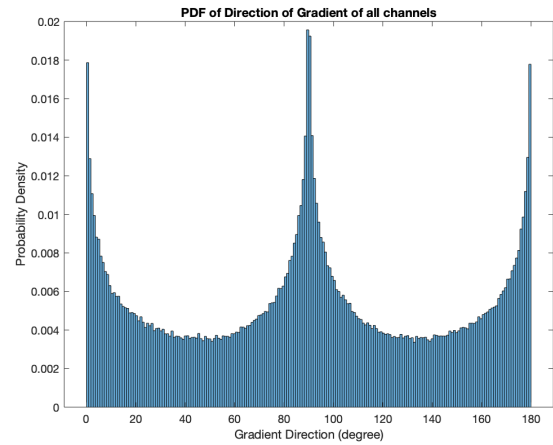
(b) Times with $PGD > 0.5$

Figure 13: Direction of wave propagation (all trials)

As can be seen in Figure 13, PDF of the direction of wave propagation for the times with $PGD > 0.5$ has peaks about 0 and 180 degrees which validate that wave propagates from right to left as same as I observed in the demo. There is a peak of about 0 degrees because when the wave is propagating from right to left, the gradients on the left side of the wave peak have a direction degree close to 180 and the gradient of the right side of the wave peak has a direction degree close to 0.



(a) All times



(b) Times with $PGD > 0.5$

Figure 14: Direction of gradients (all trials of all channels)

As can be seen in Figure 14, the PDF of the direction of gradients has peaked at about 0, 90, and 180 degrees. The reasons for the peaks at 0 and 180 degrees are explained in the last part and there is a peak of about 90 degrees because the electrodes in the first and last rows of the array can only have gradient directions close to -90 and 90 degrees.

□ Part f - Designing a test for validating propagation direction significance

As can be seen in Figure 13 b, the direction of wave propagation during the times with $PGD > 0.5$ is mostly 0 and 180 degrees. To validate this observation, I have validated the null hypothesis that the following distribution comes from a population with a mean equal to zero.

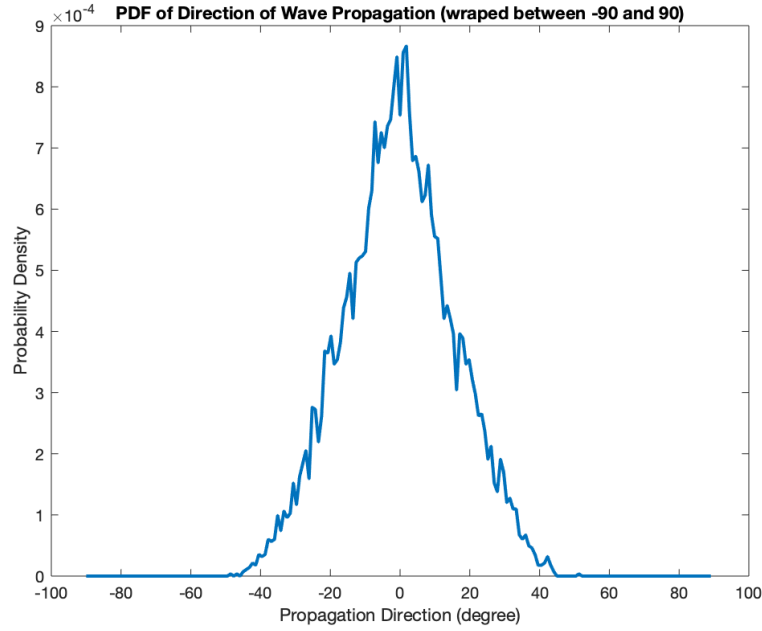


Figure 15: PDF of Direction of Wave Propagation - directions bigger than 90 degrees are subtracted from 180

T-Test validates the null hypothesis with probability equal to 0.9.

□ Part g - Comparing wave speed with criteria's in Sejnowski et.al 2018

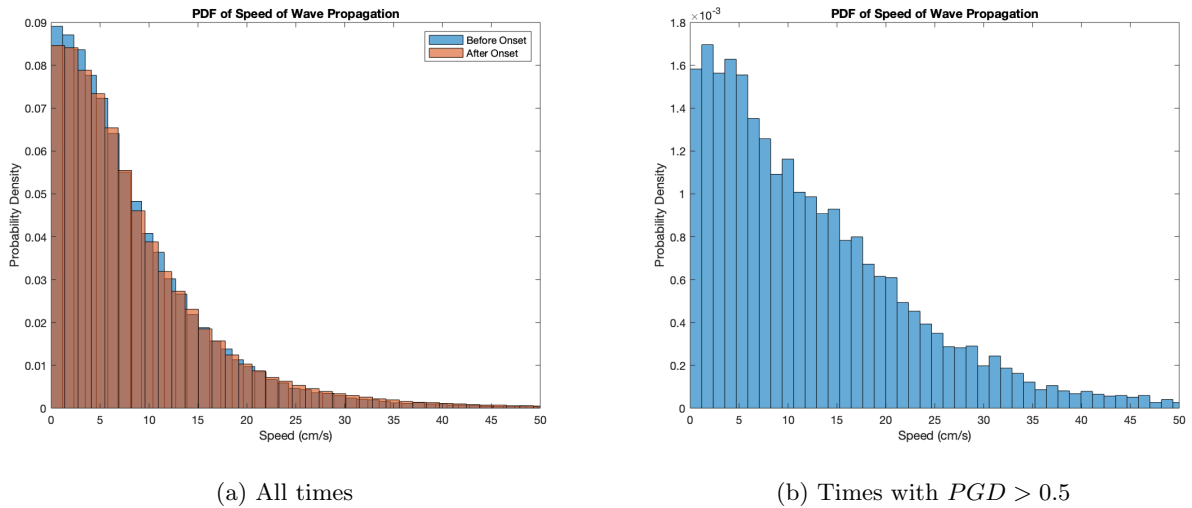


Figure 16: Direction of gradient of all channels

As can be seen in Figure 16, the wave speed is about 0 – 0.5 m/s which is mostly close to what Sejnowski has mentioned in his paper.