IBME CA1

Negin Safari 810197525

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UNIVERSITY OF TEHRAN
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Step 1

There are two different types of sleep: rapid eye movement (REM, also known as active sleep) and non-REM (quiet sleep). Non-REM sleep has four different stages that we pass in and out of through the night. There are 5 stages of sleep. Stages 1 to 4 are non-REM and stage 5 occurs in REM sleep. In the following paragraphs we will explain these 5 stages.

Stage 1:

When we first fall asleep we enter the stage 1 which is non-REM. It is recognizable by the cessation of muscle movement and slow movement of eyes behind the eyelid. In this stage we are still aware of the things going on around. In this stage brain produces high amplitude theta waves (low frequency). This is a light stage of sleep and we can be woken up by noises. This stage lasts a short time.

Stage 2:

In this stage we are actually fully asleep and not aware of what's going on around. During this stage, the heart rate and breathing regulate (slower heart rate), the body temperature decreases, the eye movements are so slow or they stop completely. In this stage brain produces rapid and rhythmic waves known as sleep spindles.

Stage 3:

In stage 3 brain waves slow down with only few activities. In this deep sleep stage muscles relax and breathing slows even more. In this stage it's really difficult to be awake and we would feel disoriented if an alarm pulls us out of it. This stage is known as delta sleep (slow wave) and body performs some important health promoting tasks in this non-REM stages.

Stage 4:

Stage 4 is the last stage of non-REM sleep. In this stage body performs some important health promoting tasks. Just like stage 3, stage 4 is also known as slow wave or delta sleep. Stage 4 is an even deeper sleep where brain waves further slow and it's really hard to wake up the sleeper. It is also believed that tissue repair occurs during this stage of sleep and hormones are also released to help with growth.

Stage 5:

The final sleep stage is REM and this is the cycle where we can dream. In this stage eyes move rapidly behind the eyelids. Also breathing and heart rate becomes rapid and blood pressure increases. The arms and legs are paralyzed so that sleepers can't act out their dreams but sometimes twitches occurs in this stage. The purpose of this stage is to stimulate the sections of the brain that are needed for memory and learning. Using this method brain can store and sort information.so we can say that in this stage brain activity increases. 90 minutes after we fall asleep.

➔ The length of these stages changes through the sleep hours but a typical sleeper will cycle through the stages several times before waking. If you suffer from sleep disorders such as sleep apnea the deeper levels of sleep may not be reached frequently and this can lead to inability of body to repair damage, few dreams, and exhaustion through the day.

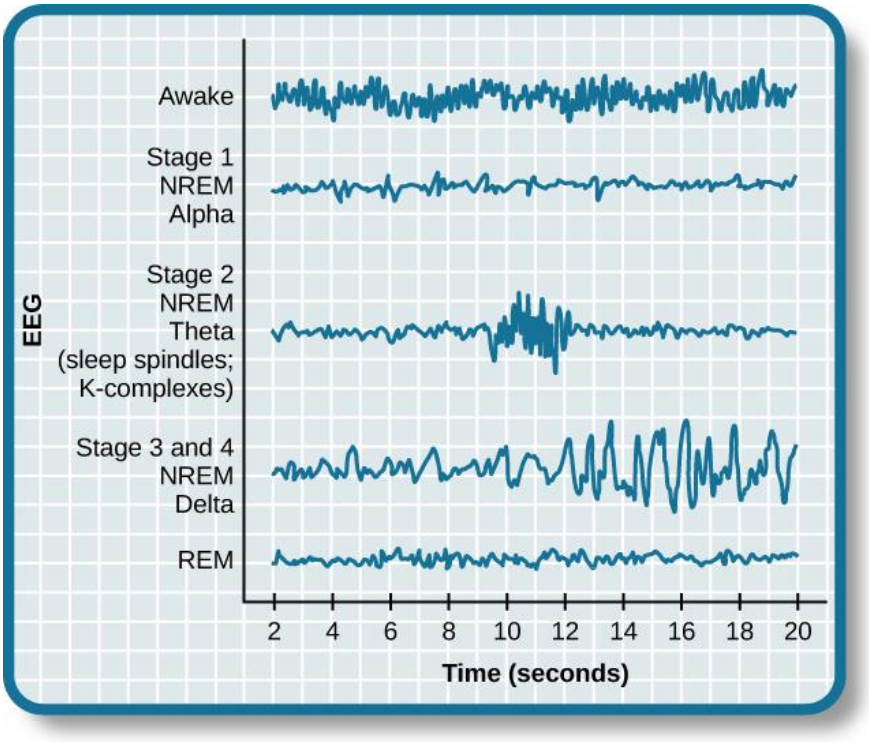

Figure 1: Brain waves in different stages

Stages	Eye movement	EEG variation
Stage 0 (wake)	Eyes are open	EEG varies rapidly Prominent beta activity with 13–26 Hz frequency and low voltage of 10–30 μV Alpha activity with 8–12 Hz frequency and higher voltage of 20–40 μV
Stage 1 (drowsiness)	Slow movements of eye rolling	Alpha waves (8–12 Hz) disappear Theta waves (4–7 Hz) appear
Stage 2 (light sleep)	Eye movement stops	Burst of brain activity visible on EEG Sleep spindles (11–15 Hz) and K-complexes appear on the background of theta waves
Stage 3 (deep sleep)	–	Delta waves appear slowly with EEG amplitude >75 μV and 1–3 Hz frequency Sleep spindles and K-complexes also exist
Stage 4 (deep/slow wave sleep)	–	Prominent delta waves with frequency <2 Hz and high EEG amplitude
Stage 5 (REM sleep)	REM with sporadic muscular twitches	Mixed frequency and low voltage Occasional bursts of saw tooth wave

Figure 2: Stages of sleep EEG variation

Sources:

[4.3 Stages of Sleep – Introductory Psychology (wsu.edu)]

[The 5 Stages of Healthy Sleep | Sleep Cycle Center (sleepcyclecenters.com)]

[Stages of Sleep - Sleep Foundation]

[(6) (PDF) Nonlinear Dynamics Measures for Automated EEG-Based Sleep Stage Detection (researchgate.net)]

Step 2

By using the code in figure 3 which is located at step2.m file, the plot of stage0 was created. This plot is in figure 4.

```
load 'matlab.mat'
Ts = 1/199.6140;
numOfsamp=size(stage0.Data);
t = (Ts)*(1:numOfsamp);
figure;
plot(t,stage0.Data);
title('Stage0 EEG data');
```

Figure 3: step 2 code

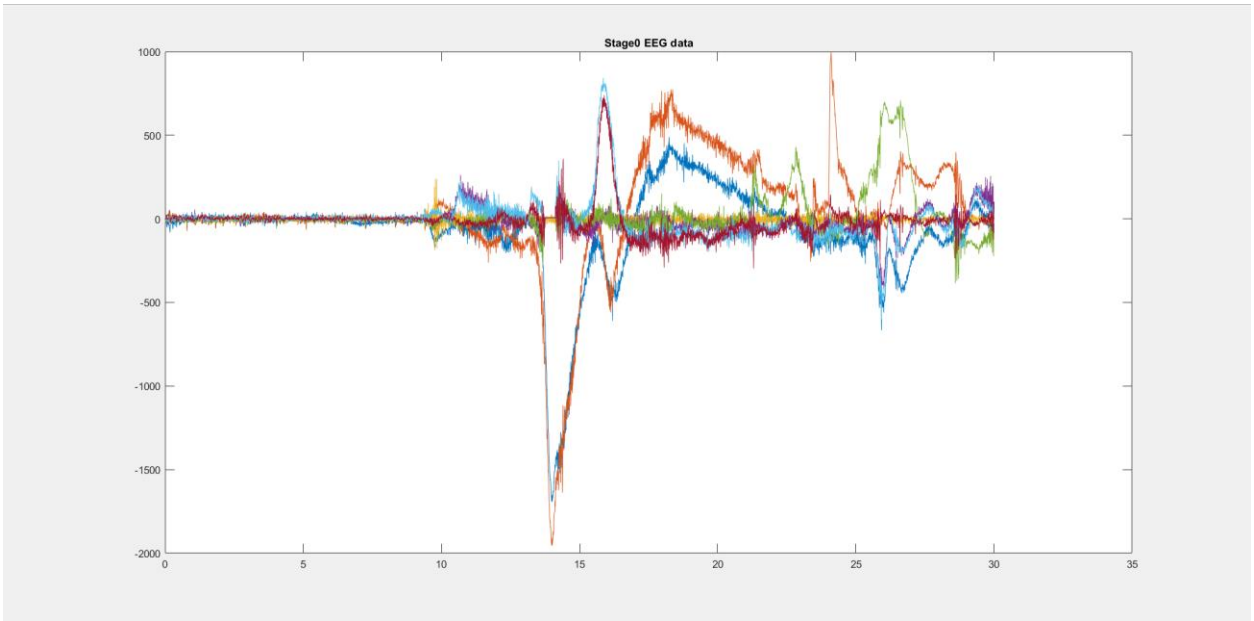

Figure 4: unfiltered data of stage0 plot

Step 3

For this part the following ranges are used.

Frequency band	Frequency	Brain states
Gamma (γ)	>35 Hz	Concentration
Beta (β)	12–35 Hz	Anxiety dominant, active, external attention, relaxed
Alpha (α)	8–12 Hz	Very relaxed, passive attention
Theta (θ)	4–8 Hz	Deeply relaxed, inward focused
Delta (δ)	0.5–4 Hz	Sleep

Figure 5: Brain frequency ranges

Source:

[Brain Waves - an overview | ScienceDirect Topics]

The code of this part is located at step3.m file. In figure 6 there are some parts of matlab code.

```
%% Filtered signal
sig=stage2.Data(:,1); % satge0 & stage1 & stage2
Ts = 1/199.6140;              % Sampling rate
L = length(sig);              % Length of signal
nsamp=size(sig);
t = (Ts)*(1:nsamp);
SIG = fft(sig);
SIGPlt = fftshift(SIG);
Fsamps=(0:L)/(Ts*L);
figure;
fplt = real((((1/(Ts*L):L)/(Ts*L))-100));
plot(fplt,real(SIGPlt));
xlabel('Frequency(Hz)')
ylabel('Amplitude')
figure;
subplot(6,1,1)
plot(t,sig);
xlim([0 30])
ylim([-2000 1000])
xlabel('Time(sec)')
ylabel('Amplitude(uV)')
title('Filtered signal')

%% delta wave ( 0.5 to 4 Hz only)
Fdelta=SIG; %changin freq rate
dLow=Fsamps<0.5; %Zeroing freq<-2.5
Fdelta(dLow)=0;
Fdelta(end-length(Fsamps(dLow))+2:end)=0;%zeroing
dHigh=Fsamps<=4;%acceptable range upper bound is 4 Hz
% zeroing unacceptable range
Fdelta(length(Fsamps(dLow))+length(Fsamps(dHigh))+1:end-length(Fsamps(dLow))-length(Fsamps(dHigh))+1)=0;
delta=ifft(Fdelta);
subplot(6,1,2)
```

Figure 6: part3 matlab code

Stage 0 result:

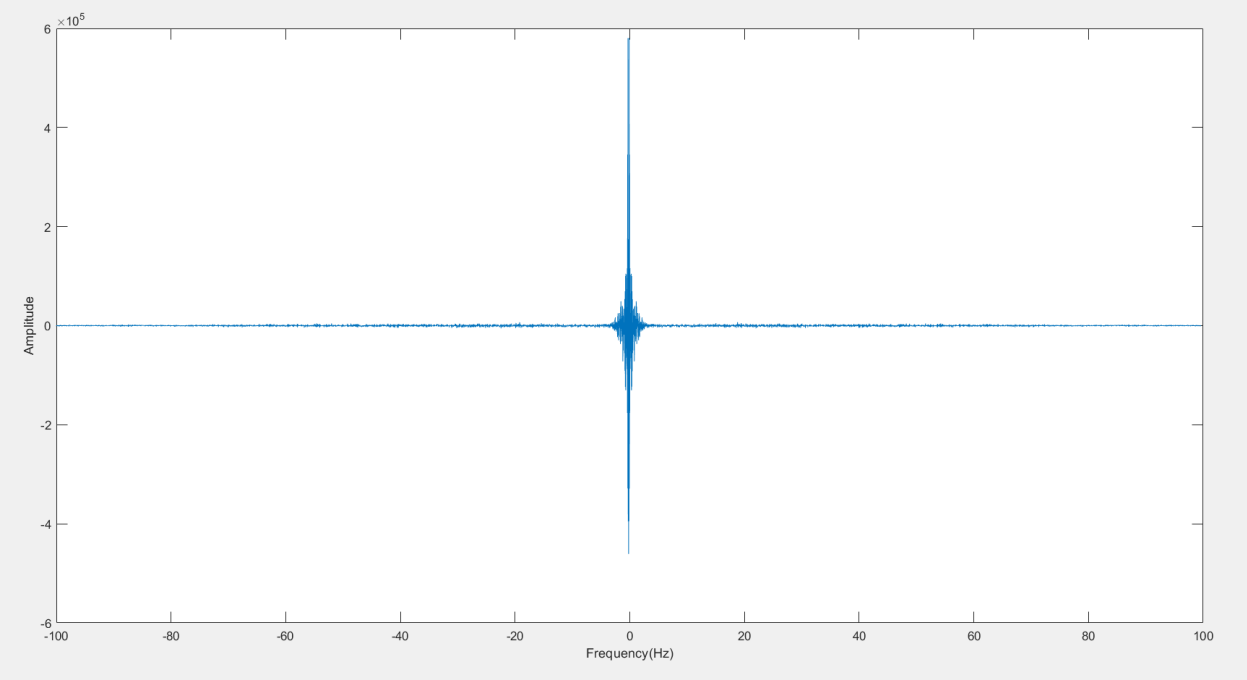

Figure 7: stage0 FFT (frequency domain)

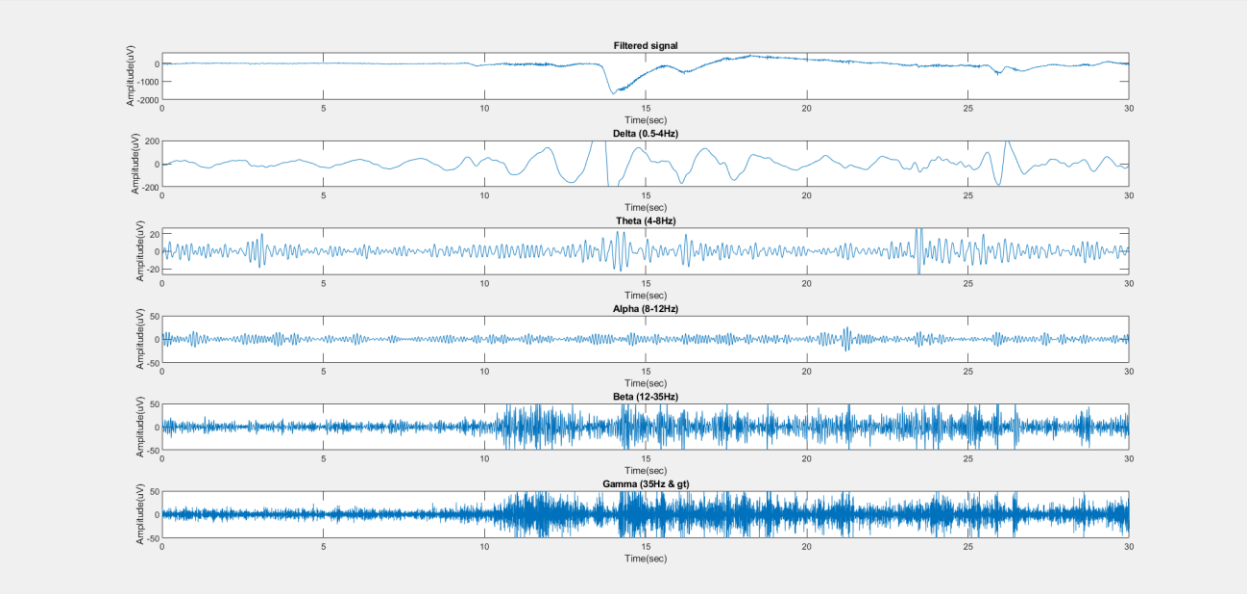

Figure 8: stage 0 waveforms

Stage 1 result:

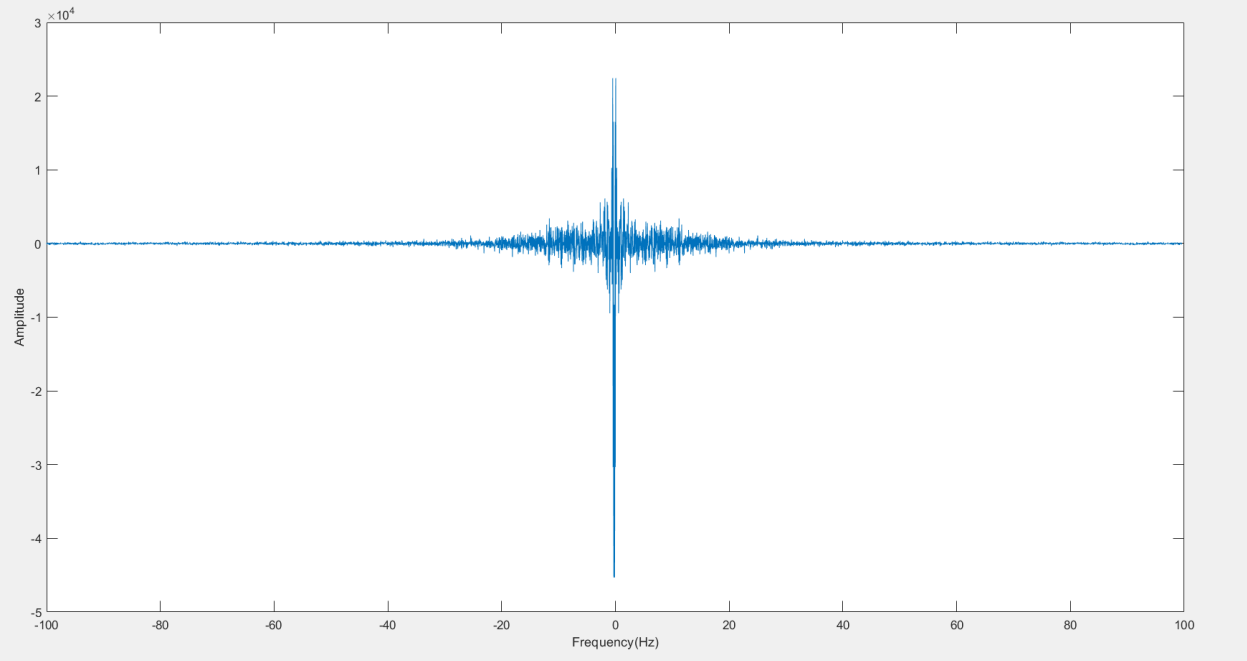

Figure 9: stage1 FFT (frequency domain)

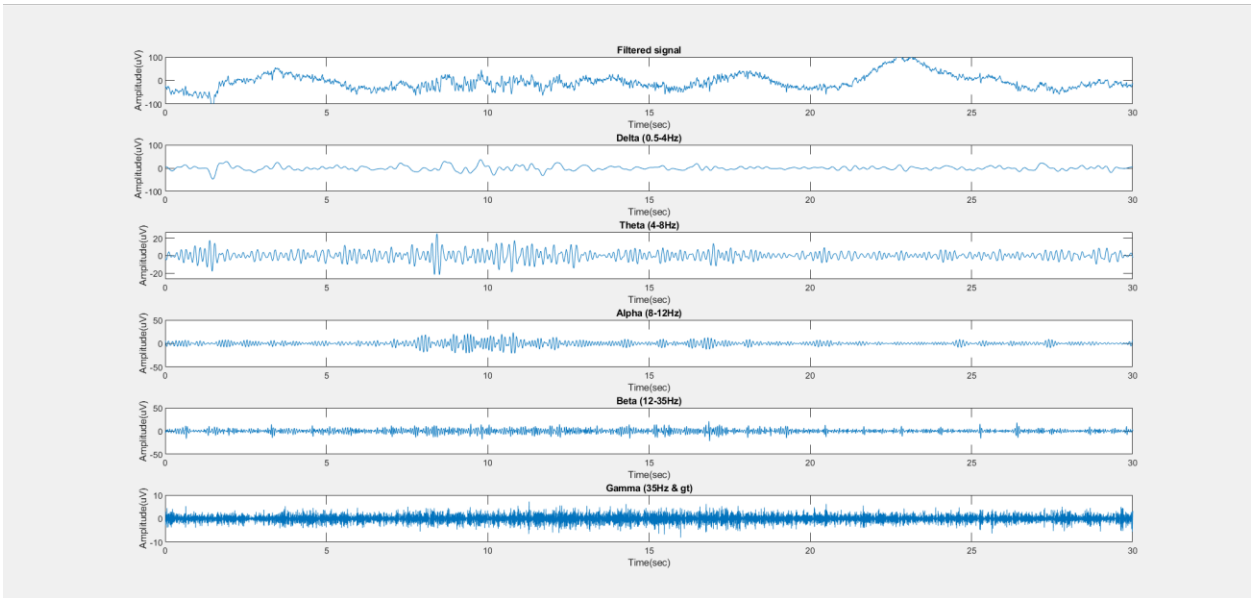

Figure 10: stage 1 waveforms

Stage 2 result:

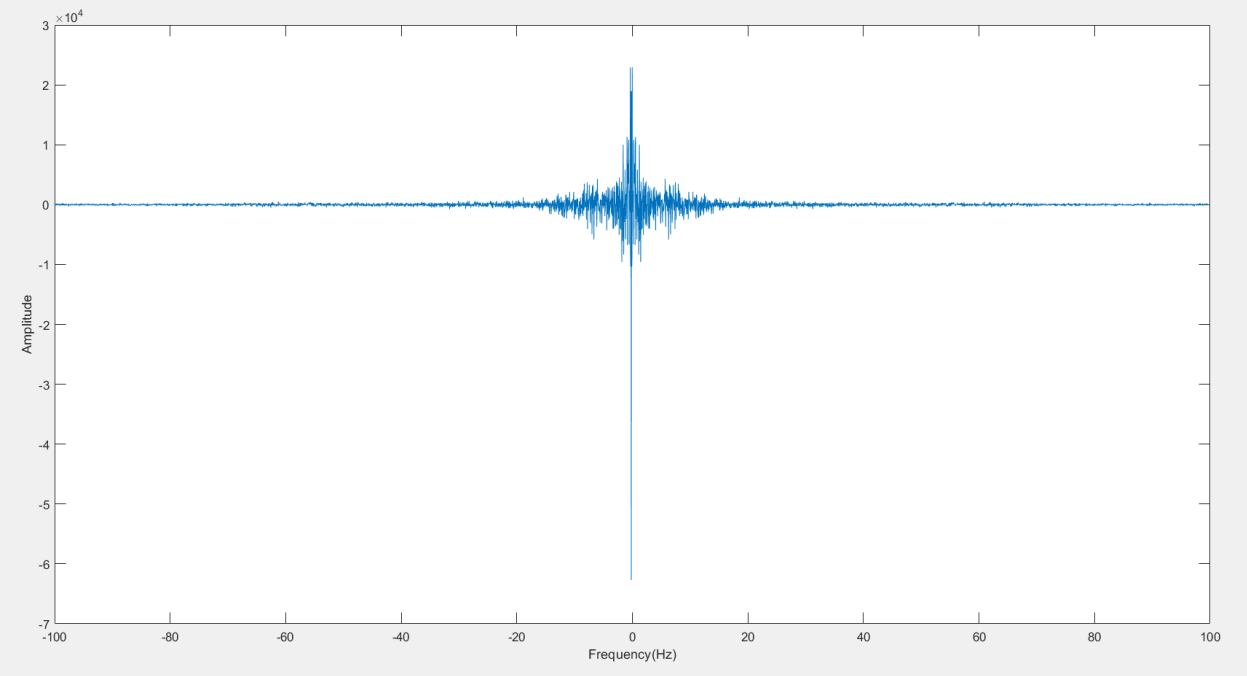

Figure 11: stage2 FFT (frequency domain)

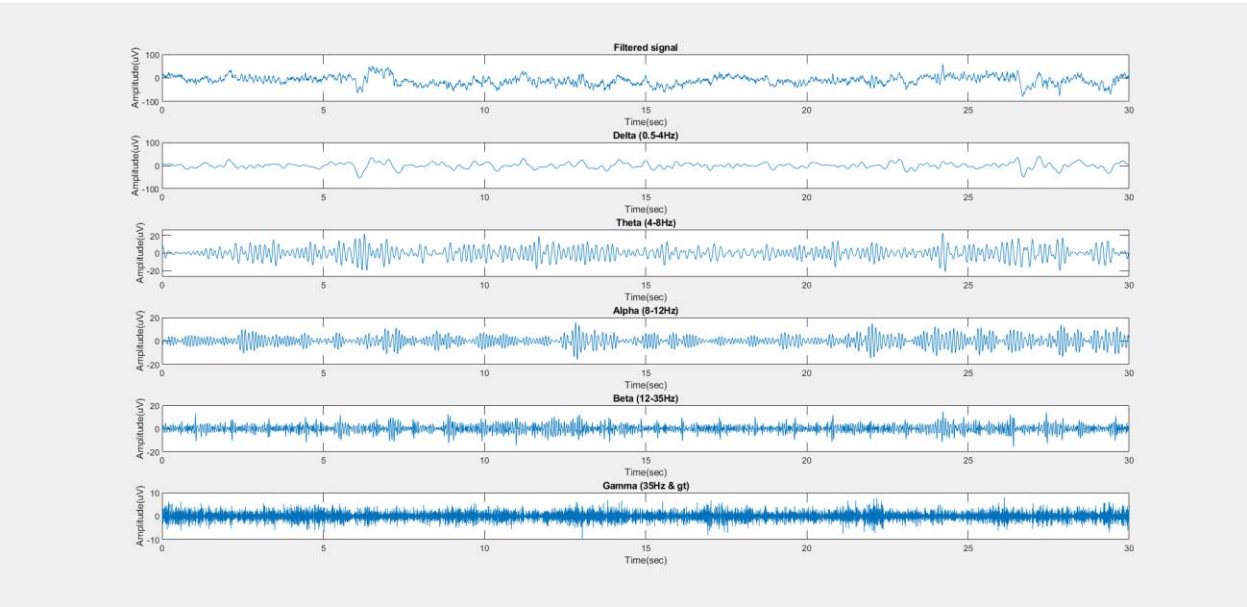

Figure 12: stage 2 waveforms

Gamma and beta waves has much larger amplitude in stage 0 (in compare with stage 1 and 2). In stage 2 Delta wave is somehow denser than Delta wave of stage 1 and the Delta wave in stage 1 is denser than Delta wave of stage 0. In stage 1 Alpha wave is denser than Alpha wave of stage 0 and the Alpha wave in stage 0 is somehow denser than alpha wave of stage 2. Theta wave in stage 1 and 2 is the densest Theta wave among stages. In stage 0 the amplitude of alpha and beta and gamma and delta wave is much more than other stages.

In stage 0 FFT we can see that the frequency domain that has recognizable amplitude is less than the FFT of stage 1 and stage 2. In FFT of stage 1 and stage 2 we can see the amplitude of higher frequencies too. In stage 1 the frequency domain that has recognizable amplitude is more than stage 1 and stage 2. In stage 2 we can easily see the amplitude in frequency range of -25 to 25 Hz. In stage 0 the data with small frequencies are a lot and it has a dense FFT diagram around 0 Hz. In stage 0 most of the data has the frequency less than 3 Hz. In stage 2 the data with recognizable amplitude has the frequency less than 20 Hz

Step 4

First by using dspdata.psd function the PSD is generated for each stage. In figure 10 there is a piece of this matlab code. This code is located at step4.m file.

```
load 'matlab.mat'
Fs = 199.6140;
%% stage0
sigS0=stage0.Data(:,1);
nfft = 2^nextpow2(length(sigS0));
P = abs(fft(sigS0,nfft)).^2/length(sigS0)/Fs;
psd0 = dspdata.psd(P(1:length(P)/2),'Fs',Fs);
figure;
plot(psd0);
title('stage0')

%% stage1
sigS1=stage1.Data(:,1);
nfft = 2^nextpow2(length(sigS1));
P = abs(fft(sigS1,nfft)).^2/length(sigS1)/Fs;
psd1 = dspdata.psd(P(1:length(P)/2),'Fs',Fs);
figure;
plot(psd1)
title('stage1')

%% stage2
sigS2=stage2.Data(:,1);
nfft = 2^nextpow2(length(sigS2));
```

Figure 13: PSD matlab code in part 4

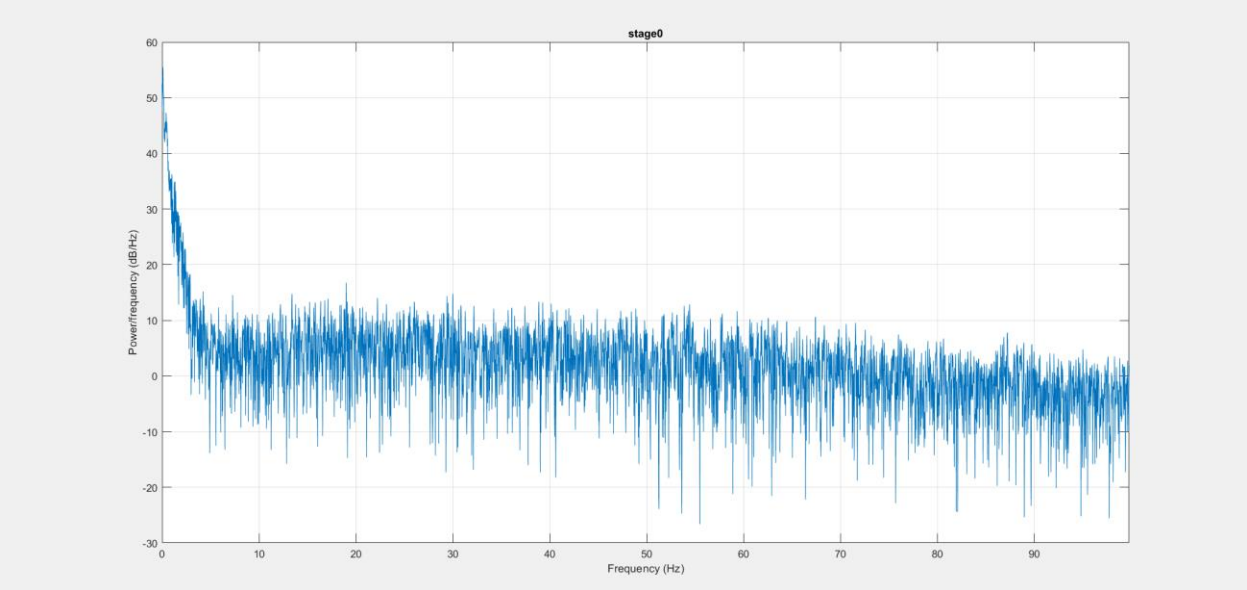

Figure 14: PSD of stage0

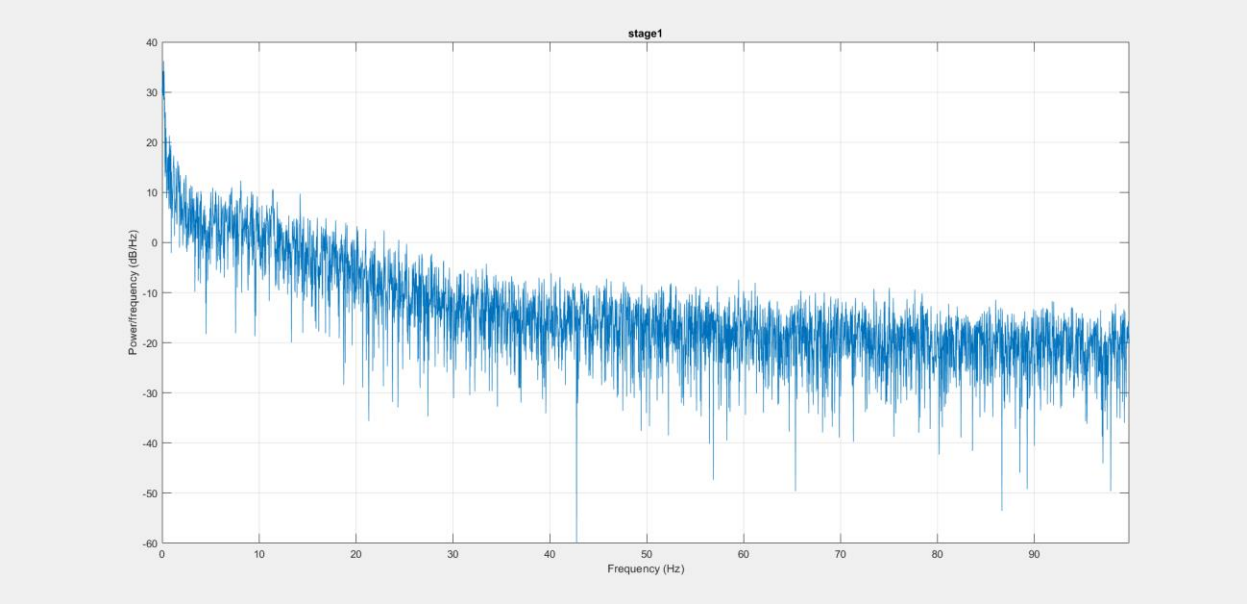

Figure 15: PSD of stage1

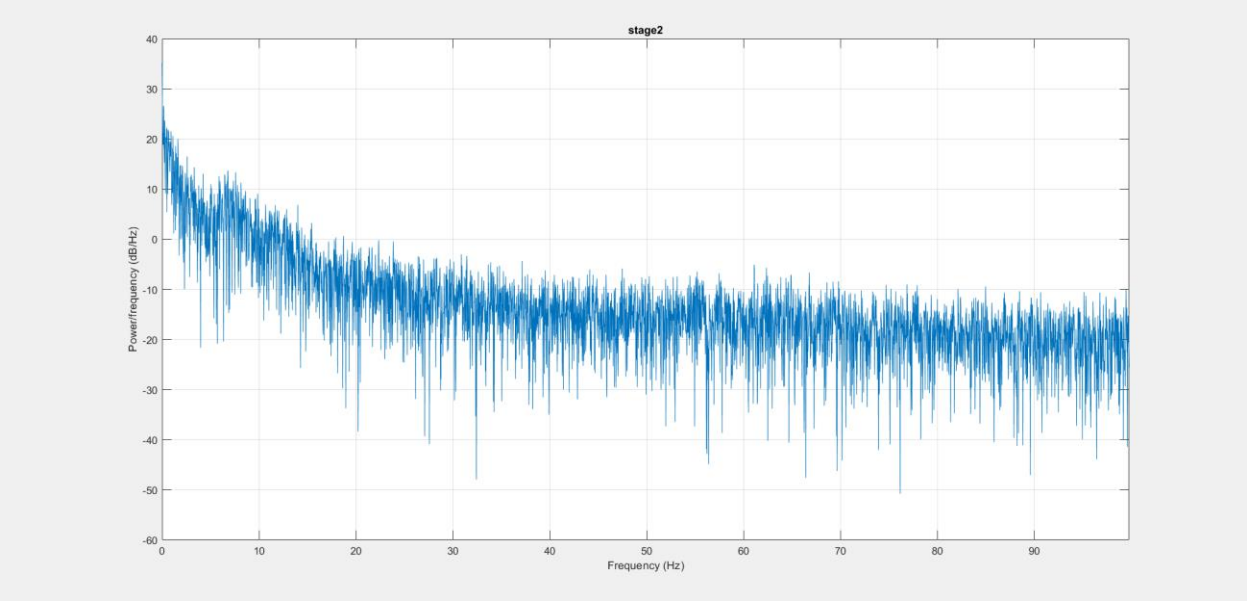

Figure 16: PSD of stage2

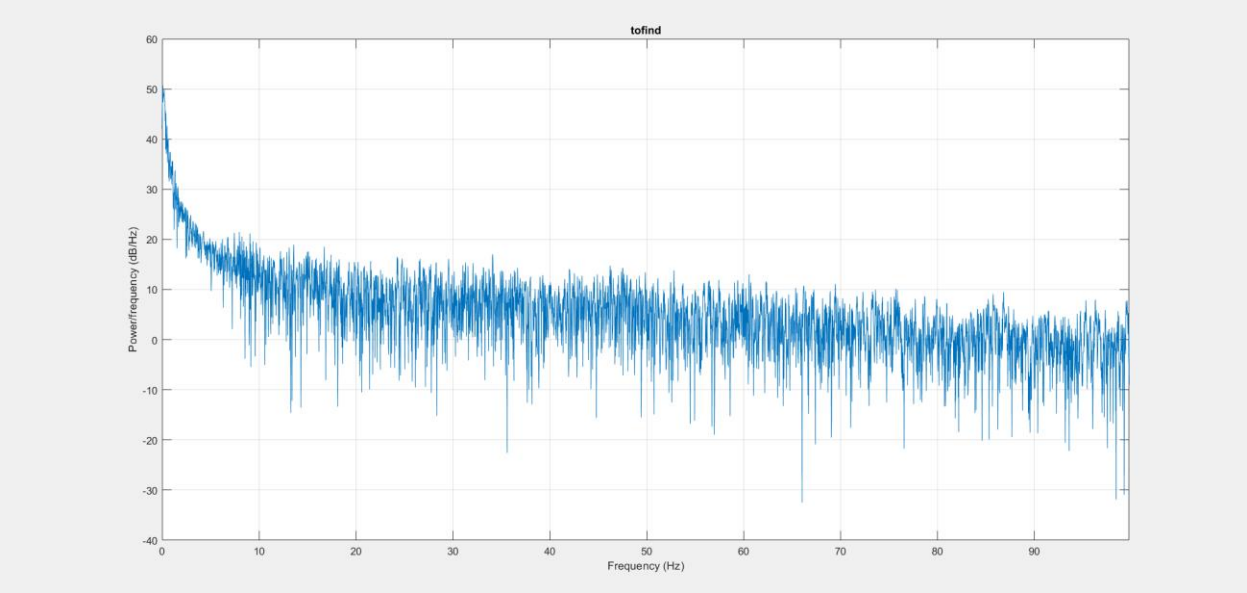

Figure 17: PSD of tofind

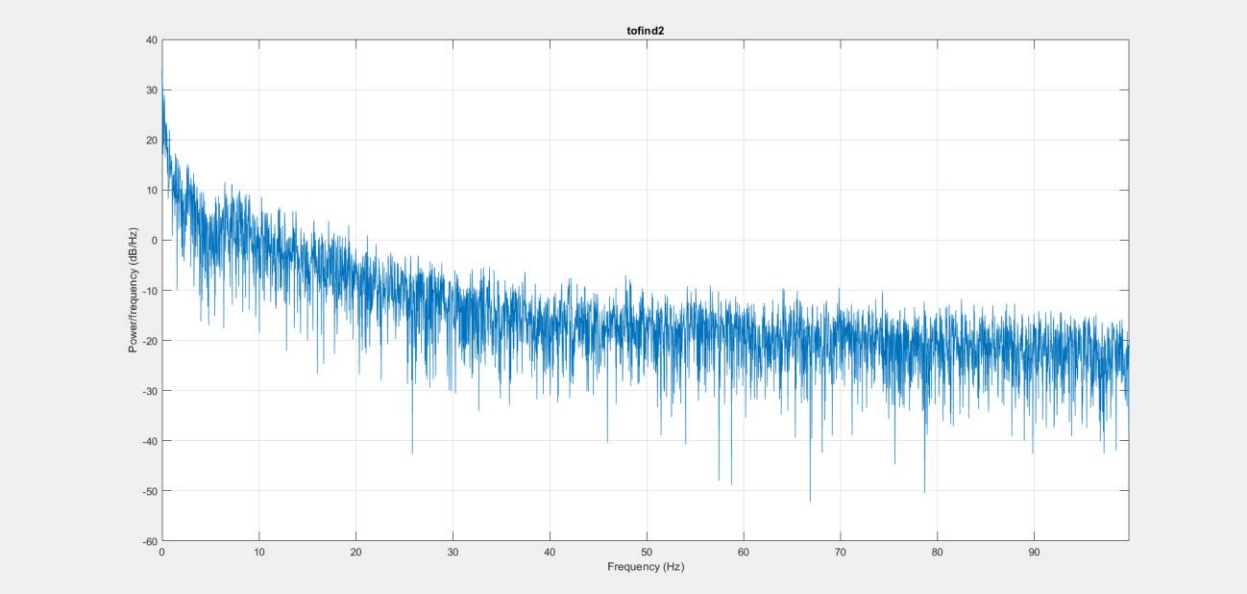

Figure 18: PSD of tofind2

Due to figure 14 to 18 we can say that each data set has different amplitude values.

In stage 0 the maximum and minimum amplitude in PSD is 55.53 and -26.61 and also in higher frequencies amplitude changes from -15 to 15. In stage 1 the maximum and minimum amplitude in PSD is 34.23 and -59.96 and also in higher frequencies amplitude changes from -6 to -27. In stage 2 the maximum and minimum amplitude in PSD is 35.16 and -47.96 and also in higher frequencies amplitude changes from -10 to 30. In tofind the maximum and minimum amplitude in PSD is 50.7 and -32.49 and also in higher frequencies amplitude changes from -9 to 13. In tofind2 the maximum and minimum amplitude in PSD is 66.88 and -52.3 and also in higher frequencies amplitude changes from -12 to 34.

In stage 0 power density between 0 and 5 Hz is much more than stage 1 and stage 2. As the frequency increases in stage 0 the power density decreases.

In stage 0 power density between 5 and 10 Hz is generally more than stage 2 and power density between 5 and 10 Hz in stage 2 is more than stage 1 and this continues to around 40 Hz frequency.

Step 5

Due to the PSD (figure 14-18) and data bands (figures 8,10,12) of three stages:

Delta band has some peaks in 12 to 15 seconds and around 26 seconds. In stage 1 until 12 s the peaks are bigger and also in stage 2 it has the same rate and the amplitudes are really close.

Theta band has some peaks around 5 s and 14 s and 23 s in stage 0 and in stage 1 it is denser in first seconds from 0 to 3 s and around 10 s. as the time pass its amplitude gets smaller. In stage 2 we can say that it is generally denser than other stages.

Alpha band in stage 0 has more density and some peaks around 14 to 19 seconds. In stage 2 the most density is around 4 s and 7 s and 13 s. also after 20 s we can see some large peaks.

Beta band in stage 0 has less amplitude at the beginning but it become denser after 10 s. in stage 1 the most peaks are between 4 s and 18 s, as the time passes the amplitude reduces and there is no noticeable changes in times larger than 20 second.

Gamma band in stage 0 has more density between 15 to 20 s. in stage 1 the most peaks are around 8 to 10 s. gamma band in stage 2 gets denser and has larger peaks after 20 s till 30 s.

If we compare the figures we assume that each stage would reach a stable state but stage 0 reach this stable state sooner than the others.

The speed of stage 1 is more than stage 2. In lower frequencies we can see that the density of stage 0 is less than the other stages. And also stage 0 has the least peak to peak distance. Stage 1 has the most peak numbers.

Stage 0 has the largest amplitude and in lower frequencies it has negative values.

In stage 0 Gamma and beta waves are much denser than the other waves in stage0. In stage 2 Delta wave is denser than Delta wave of stage 1 and the Delta wave in stage 1 is denser than Delta wave of stage 0. In stage 1 Alpha wave is denser than Alpha wave of stage 0 and the Alpha wave in stage 1 is denser than Delta wave of stage 2. Theta wave in stage 1 is the denser Theta wave among stages.

If we look at PSDs in pictures 11 to 15, we assume that in stage 0 the amplitude starts from 55, in stage 1 the amplitude starts from 50 and in stage 2 it starts from 40. If we compare the figures we assume that each stage would reach a stable state but stage 0 reach this stable state sooner than the others. Stage 1 is faster than stage 2 in reaching this stable state.

Step 6

First, by using pwelch function some plots are made. The code is in step6.m file.

```
load 'matlab.mat'
%% stage0
[s0,~] = pwelch(stage0.Data(:,1));
figure;
plot(10*log10(s0));
title('stage0')
xlim([0 1200])
%% stage1
[s1,~] = pwelch(stage1.Data(:,1));
figure;
plot(10*log10(s1));
title('stage1')
xlim([0 1200])
%% stage2
[s2,~] = pwelch(stage2.Data(:,1));
figure;
plot(10*log10(s2));
title('stage2')
xlim([0 1200])
%% tofind
[tof,~] = pwelch(to_find.Data(:,1));
figure;
plot(10*log10(tof));
```

Figure 19: pwelch code in part 6

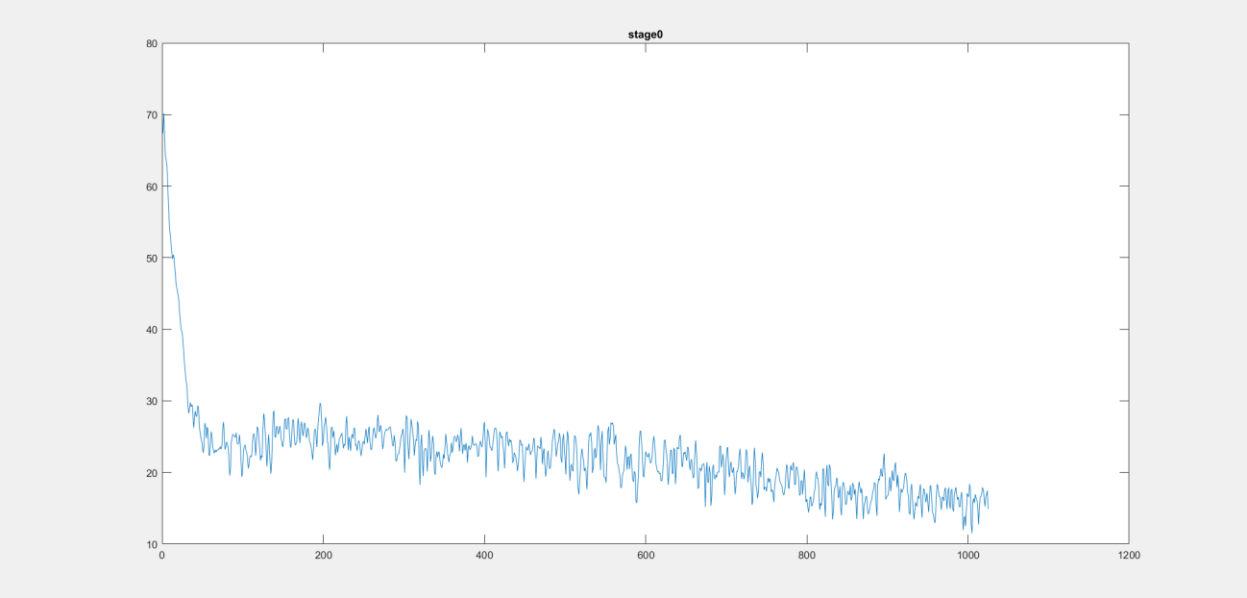

Figure 20: power of stage0

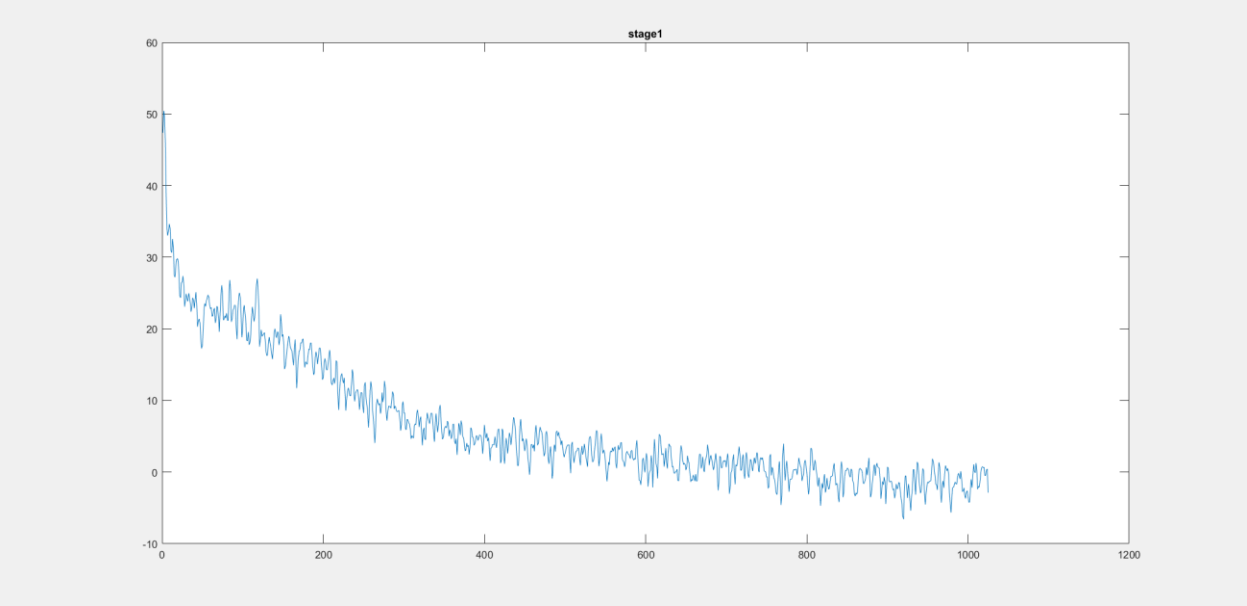

Figure 21: power of stage 1

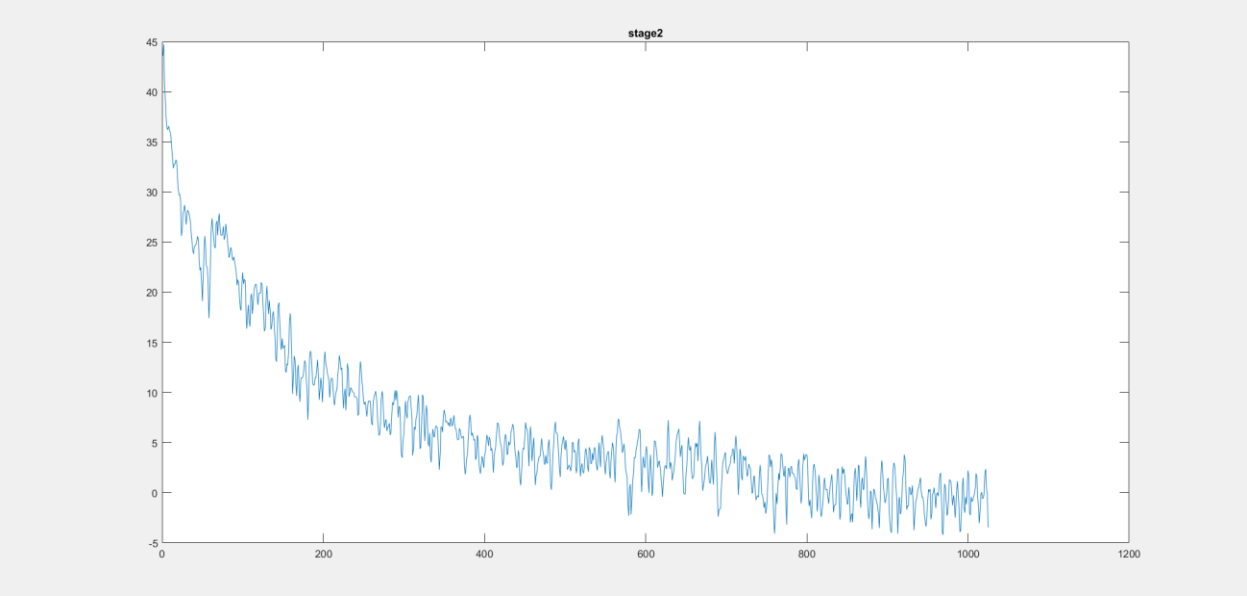

Figure 22: power of stage 2

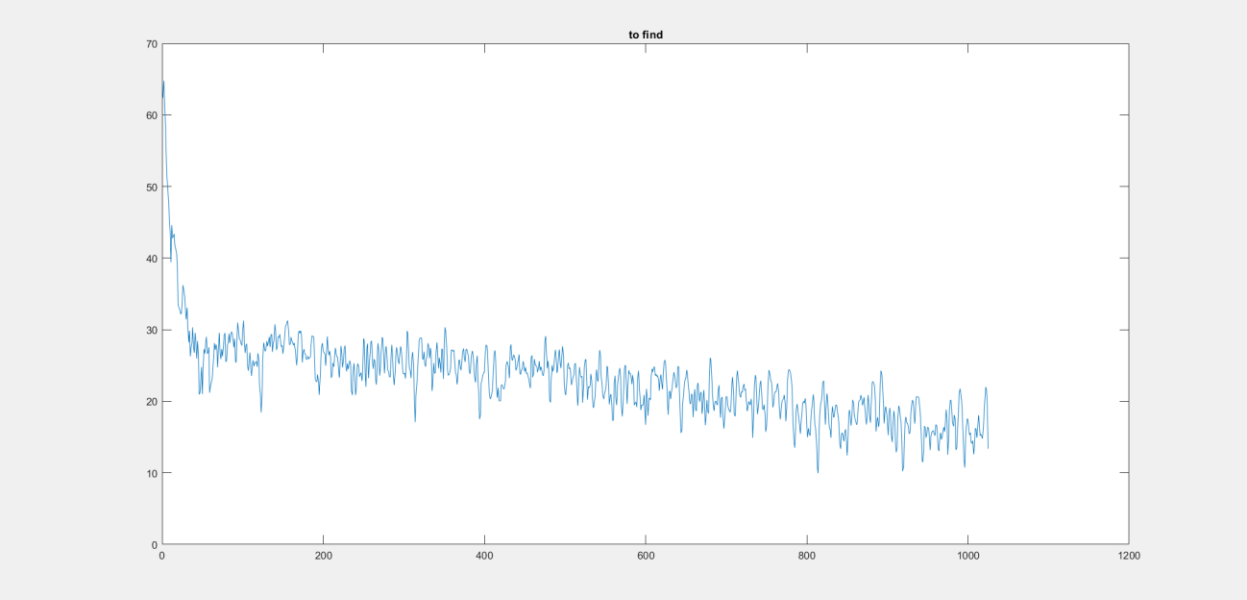

Figure 23: power of tofind

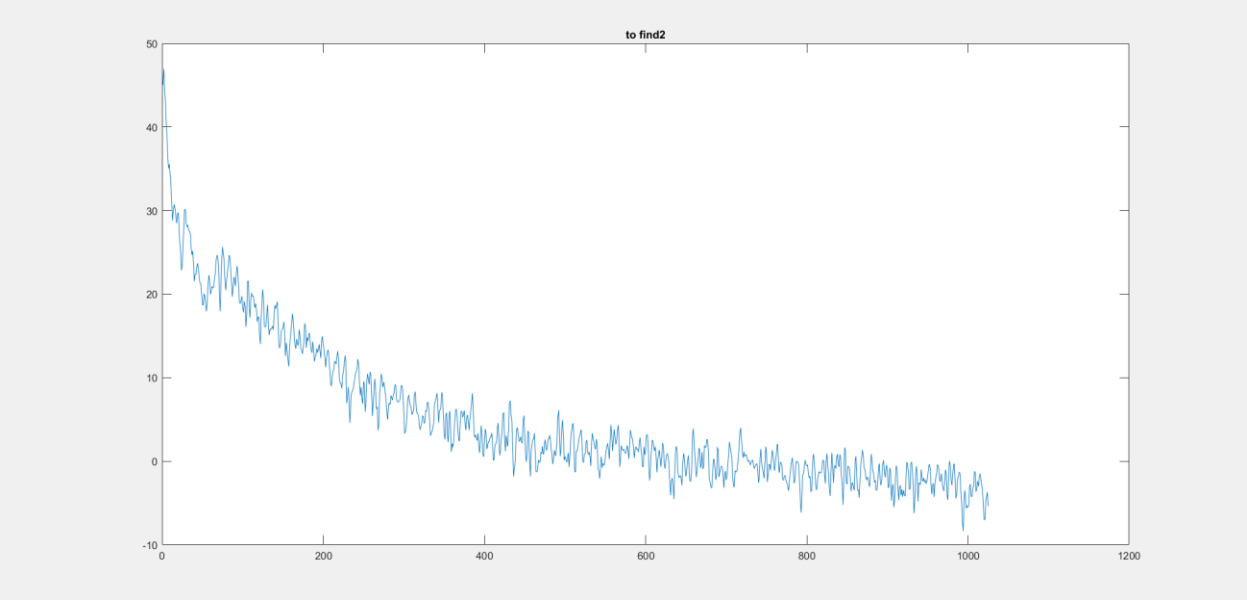

Figure 24: power of tofind2

To make sure about our decision, we plot different boundaries of tofind and tofind2 EEG waves, just like what we did in part 3. The code is in file named step6Tofinds.m.

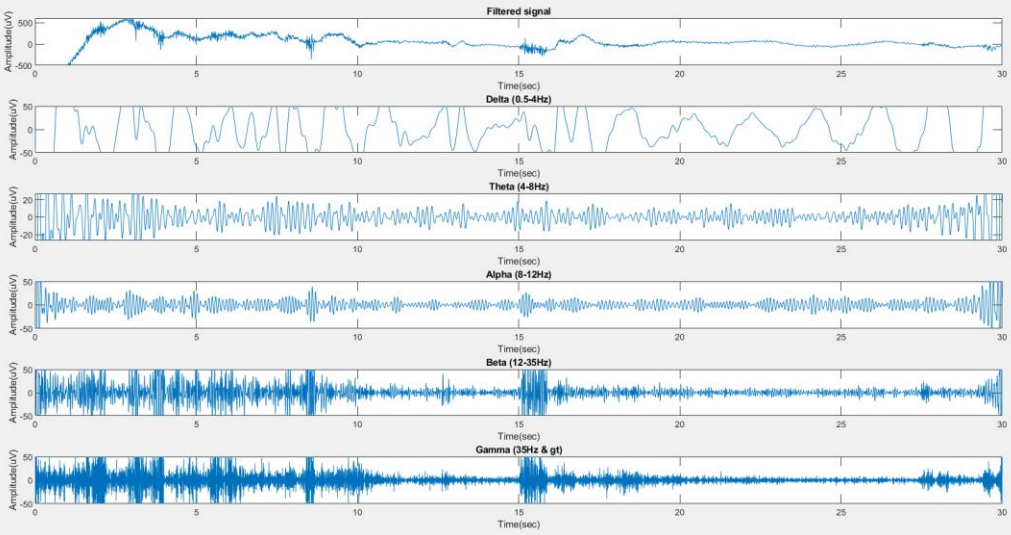

Figure 25: tofind waveforms

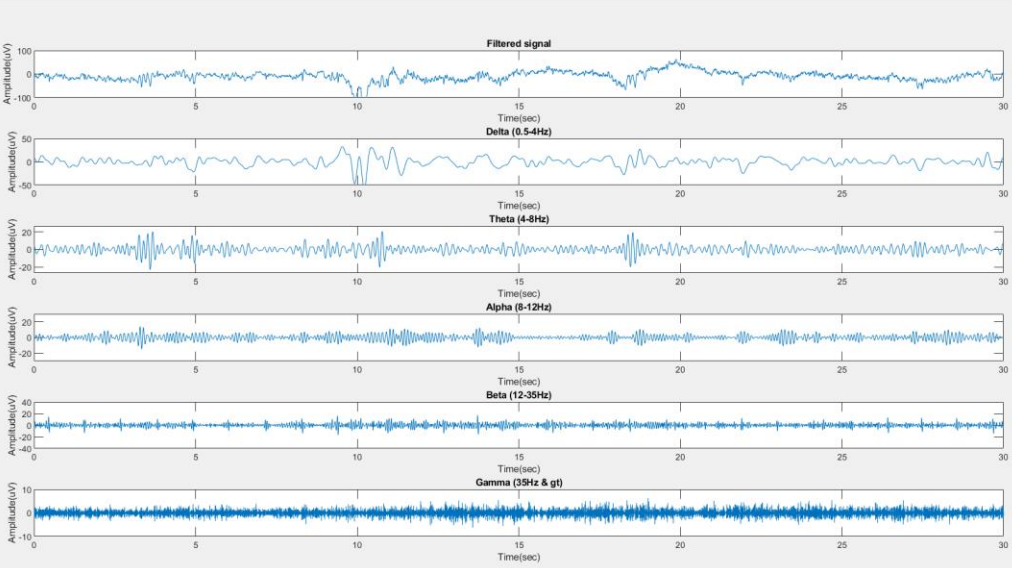

Figure 26: tofind2 waveforms

If we compare all of these figures (pwelch figures and FFT figures in different frequency boundaries and amplitudes. As you can see figure 25 is more similar to figure 8 and figure 26 is more similar to figure 10. The properties of PSD of tofind (figure 23) is much more similar to PSD of stage 0 (figure 20) and the properties of PSD of tofind2 (figure 24) is much more similar to PSD of stage 1 (figure 21).

So we can say that to_find is similar to stage0 and to_find2 is really similar to stgae1.

To find == stage 0

To find 2 == stage 1

Guide for uploaded files:

All of the matlab codes are located at “matlabCodes” folder.

Code of step 2 >> step2.m

Code of step 3 >> step3.m

Code of step 4 >> step4.m

Code of step 6 and using pwelch function for all datas >> step6.m

Code of step 6 and finding different waves of tofind and tofind2 >> step6Tofinds.m