Advanced Neural Science for Engineers
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Lecture – 53
Mathematical Analysis in Neural Science

Hello everyone. Welcome to this short quick module on Computation in Neural Engineering. You will see some of the basic aspects of mathematical analysis in neural science and it will be a short quick module but very useful when it comes to your you know project implementation, or any brain computer interface based or either intelligent potential based project. So, before showing you the analysis part I will quickly.

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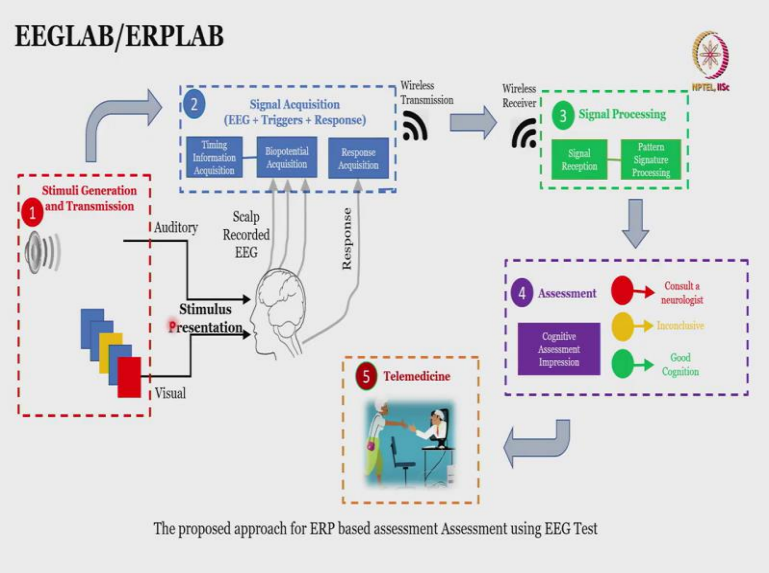

The proposed approach for ERP based assessment Assessment using EEG Test

Provide you the recap this is what we have already learned in one of the course that will generate a stimuli followed by signal acquisition which will be wirelessly transmitted to a computation system and where you process and make the sense out of it. Assess something and it based on based on the application your final assessment varies.

If it is like attention cognitive decline, there can be this kind of three indicators whether a person should consult a neurologist whether it is inconclusive or repeat the test or good cognition or if it is hearing screening than a baby or you know a person can hear, person cannot hear and there is some issue.

Same ways a small aspect which we are not touched upon too much was telemedicine that once this is diagnosed you can transmit it securely to a clinician or a person who is you know placed at a remote area. Mainly, useful in resource constrained area or villages something like that. So, this was like overall approach today the entire emphasis would be on this third part which is on Signal processing. How we will achieve that how we will make a neural sense out of the recorded data. So, I will emphasize as I mentioned on this point number three.

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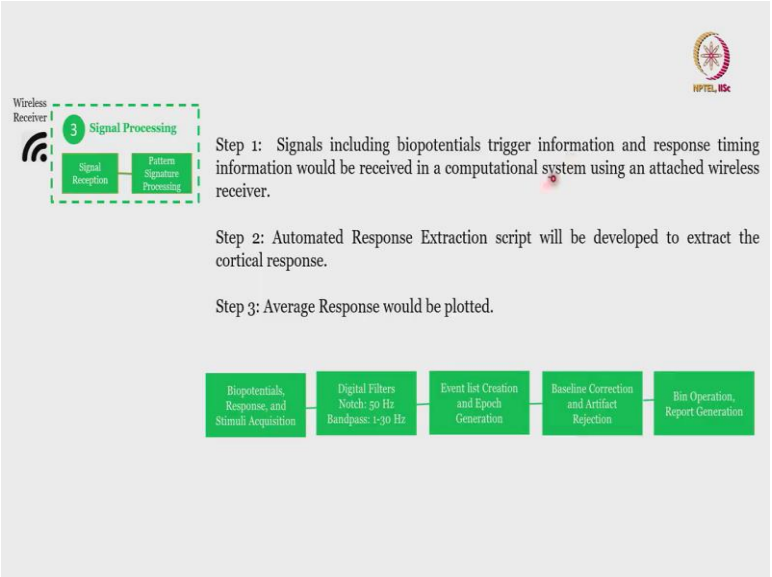

What do we do in that particular Point number three. So, in that three these are some of the basic building blocks which we will be implementing in a software called MATLAB. So, when I say MATLAB along with MATLAB there are some of the plugins which will be used. So, that I will already will discuss it in the upcoming demonstration a quick demonstration Code walkthrough.

Here you see this is like some of the basic steps written for Signal processing aspect what we will do is we will acquire bio potentials response and stimuli acquisition. Stimuli acquisition means all your triggers at which particular point of time which kind of trigger was provided. So, that is very important along with bio potential you should also record a trigger.

So, that is for that particular thing also once you are you have to apply filters to make a neural sense out of it you have to remove the non-neural component for which you can use 50 hertz Notch filter. Now 50 hertz notch filtered why because in Indian setting electrical power supply is 230 volt 50 hertz when you talk about Western World when there is a 60 hertz power supply you have to replace this Notch filter with 60 hertz power supply.

Prior to that you need to make sure that you are not getting any kind of power line interference you have to Shield your wires which are guiding or taking your bio-Potential from your scalp to the acquisition system should be completely prone free. Also, you can use a band pass filter because most of the scalp recorded potentials which comes for our application or normal cognition application should be recorded within this particular point of range.

When I say that based on application this range differs. If I am recording auditory brainstem response this range would be different. So, based on your target application range of your filters changes, also there is event list creation what is that I will come through that and quickly walk through you have to do some epoching, baseline correction, artifact rejection and Bin operation.

So, this is like an overall idea of what we are going to do or going to implement prior to moving to the Code walkthrough I will just quickly tell you what is the experiment. Experiment is on visual evoke potentials to assess working memory and all.

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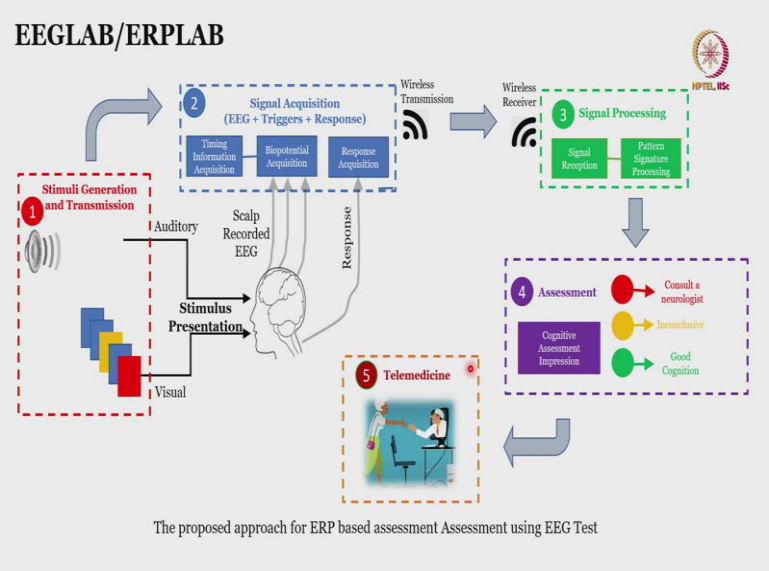

The proposed approach for ERP based assessment Assessment using EEG Test

So you can see here three type of images has been shown to a particular subject. So, there are three type of images which one one of them is you know more frequent which is the blue one and other two are the rare or you know kind of less probable or less occurring images. So, there are you know stimuli design is also another aspect which we can you know itself go into the detail.

But for now, for the Code walkthrough what we have been doing it is an experiment conducted to assess working memory and attention which is being measured using P300 event related potential. Which is you know happened when you have three types of images Standard, Target and Destructor.

Subject is asked to click on a mouse or count the number of occurrences when Target images come. Let us say in this case red particular red rectangle is the target image then in between yellow occur yellow image also comes so then what is the significance for that so that is your distractor it tries to distract you and you are not supposed to click or you are not supposed to respond when the distractor comes.

So, it also checks your runtime memory and also attention so this is very briefly the overall experimental protocol how many electrodes have been used you can see here three electrodes have been used which generally placed on Cz, Pz and Oz because this is a visual experiment, I have already discussed that for visual experiment the electrode should be placed in your back side by the central or occipital or parietal region. So, today the more focused is on code so I will quickly switch to the Code walkthrough.

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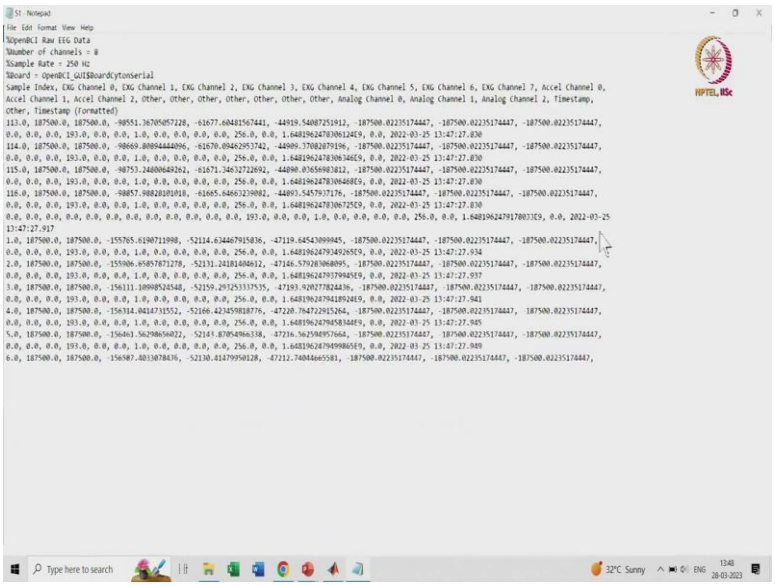

So, this is what the you know recorded files looks like. Now, I will just show you what is there this was recorded using open BCI cyton board so which has a 250 Hertz of sampling rate which means that every four millisecond you will get one sample so it is for one particular subject subject one and its opening you can clearly see once it gets open that it will record eight channels yeah it is taking little yeah you can see this.

So here you can see total 8 channels 250 Hertz also it is in comma separated format these all are headers which you can see here sample index external channels 1 to 8 8 0 to 7 means 1 to 8 then accelerometer channels other things other things are basically your digital triggers, analogue channels time stamp and all this thing.

This is mainly this is like your original timestamp this is a timestamp formatted. So, if you see the same thing is been followed and you know this this is some data here some data here some data here again this all are like you know same thing which is not connected. So, based on just a rough observation visual observation I can say that yeah Channel data might be there in this 3 4 and 5 channel. Because this is your first channel second channel 3 4 and 5. So, while acquiring data we need to take this data and then also you have to take digital triggers which will be a part of here.

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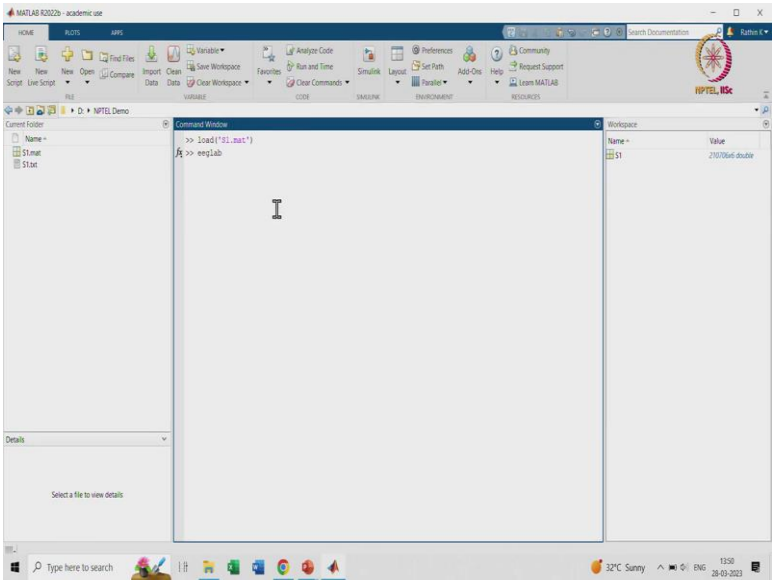

So, I have already extracted this and data is saved here. So, let us quickly load that so you can see this data is stored here which has some 2 lakh samples into 6. Now, what are the 6 things so first three are the bio potentials and the other three is mainly used to give the triggers. Before we start performing experiment, we need to make sure that EEG lab is added to the path.

Now, when we upload this video in description on a comment, I will put a link to my previous introduction to EEG Lab video which will help you just to from where you can install EEG lab what is EEG lab it is developed by SWASH Centre for computational Neuroscience to play with EEG signals.

It can be of any system currently I mentioned open BCI cyton system it can be of any other system as well using which you can take the data in EEG lab with different plugins and play with it. So, I have to add this particular EEG lab into the path so EEG lab is added here its updated latest 2022 version you have to add to the path with subfolders.

Once that is done you can we can come back to the data. So, now what I will do is I will open the EEG lab I will show it one approach using GUI. I will also inform how you can perform batch file processing and all in both cases you can do pre-processing in both cases you can do feature extraction in both cases you can do classification in both cases you can do ERP extraction-based pipeline everything.

Whatever you can do in GUI same thing can be converted into a code and then you can give a provision of batch file processing. Currently, there are research going on on online processing as well so for that online means current data is recorded and then we are processing it offline. How can we record the data and similarly processes at same particular time. So, that is research and which is currently going on to have on chip filtering on chip pre-processing and on chip signal processing.

It also you know considers how easy you can have a communicate how easy you can get computations and how you can may you know decide a trade-off between hardware and software. Because, you know filters. Filters can be implemented using Hardware filter can be implemented using software also we will see how to implement using software.

So, in both cases you can apply filters so how we what would you prefer in Hardware filter also there are active filters and passive filters which one will you prefer you should have answer for all this thing before you perform any kind of Hardware software code design right. Software is very easy you just take the data into system and perform it so why should not we go with software or why should not we go with Hardware.

Hardware will give you more you know Precision or something that depends what is your role of factor what is your pass bandage gain what is your stop bandage so many things are there right. So, also your I have just talked so far about amplitude of the amplitude response of filter also you should consider is Phase whether your filter gives you linear phase or not.

And filter is just one example you can we are doing so many several things and currently I am showing it for 3 channels the existing micro electrode arrays uses more than 3000 you know around 3000 Channel 4000 Channel how will you take care about the computation of

those 4000 Channel how will you make sure that out of this 4000 Channel this much information is only useful the other things that we do not have to consider.

So, all these things are happening, and you know currently in research and which is used for online signal processing on chip signal processing rather. Where electrode would be on your head along with electrode there will be one small processor or signal processor DSP what you say it will be also placed there and using that you can extract the signal.

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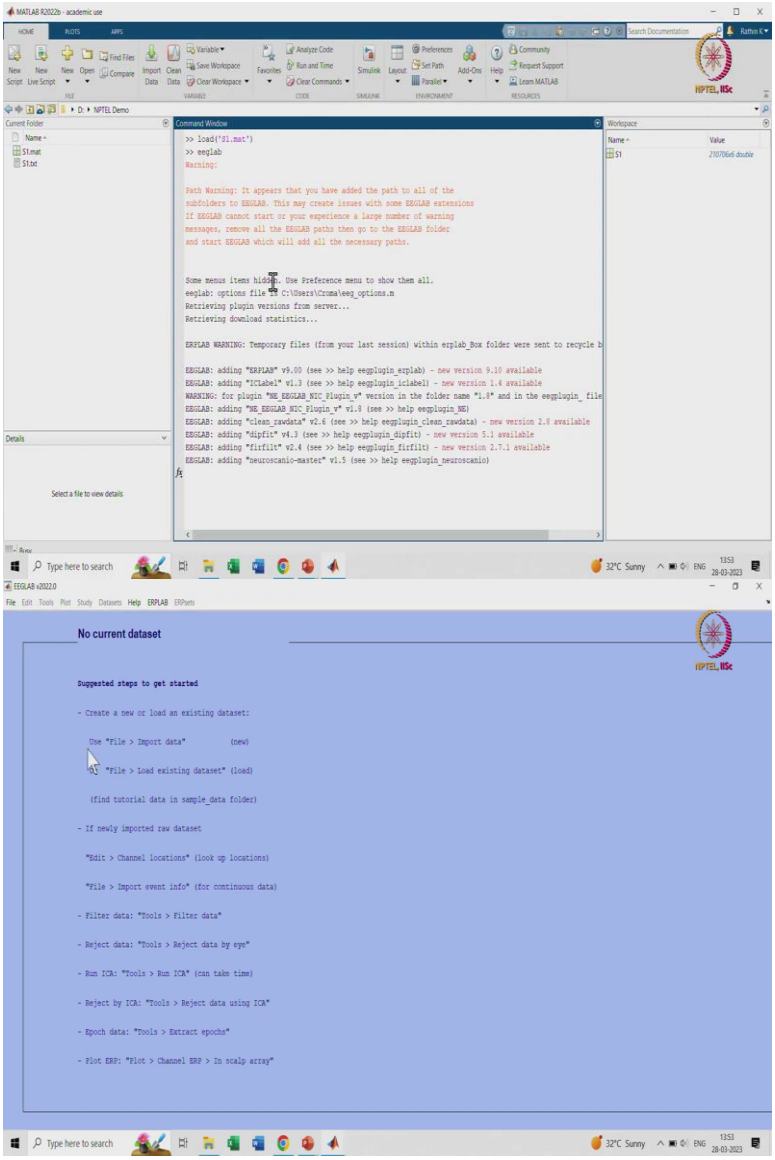

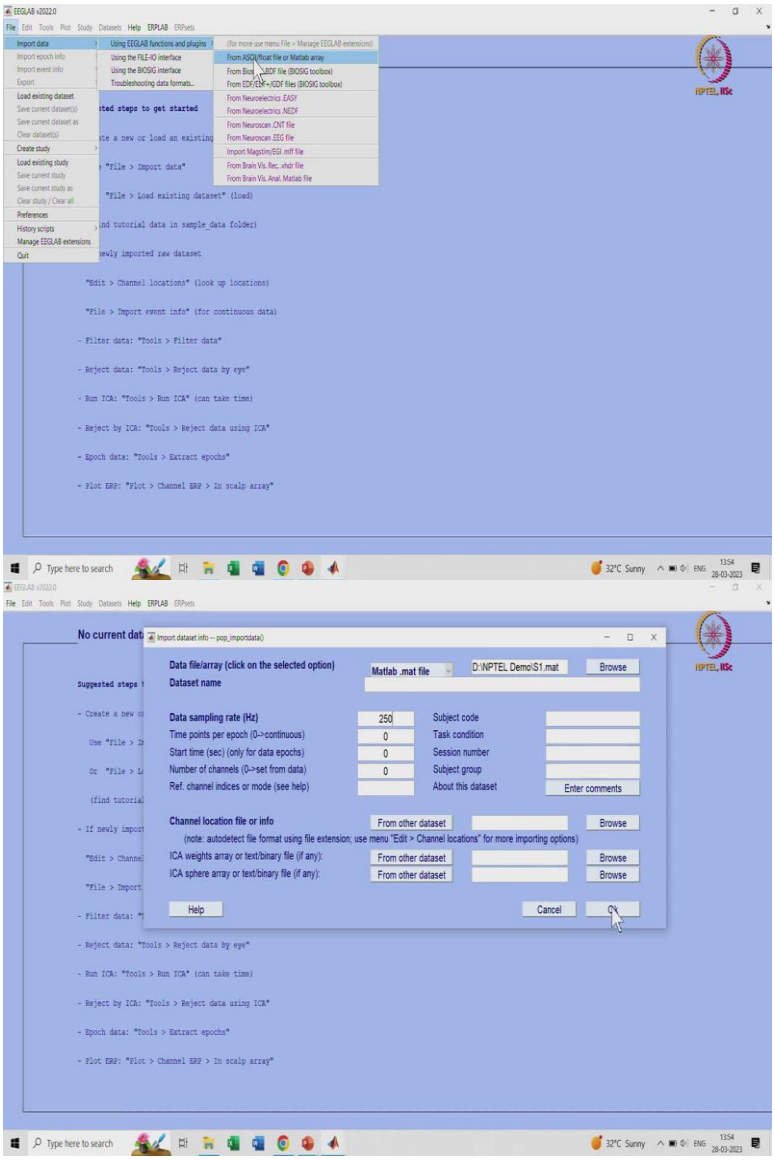

So, coming back to this code walkthrough here you can see I have already added EEG lab into the path and then we will run the EEG lab, EEG lab is a plug into MATLAB and as I mentioned specifically designed for neural signal processing. So, this I have installed 2022 version if you have latest version, you can upload it.

This is the home screen it is like a normal software which has a horizontal menu bar with a title nothing else. You can take the data from this file other options will get enabled once you have the data. So currently, we have a data stored in MATLAB here as you can see it is a mat block dot mat file which is a MATLAB array.

So, I have to acquire it using this file import data. So, using EEG Lab App functions and plugins first one is only MATLAB area or ASCII file. So, I have to just select this MATLAB array it will ask me few questions this is Pop import data. So, when you convert this into a code you have to write the line for pop import data.

Here it will ask me that from where do you want to get the data so we have already this data ready dot mat file also we can give a sampling rate. So, as I mentioned it is recorded using cyton. So, it records at 250 Hertz if you have higher sampling data you can go ahead with that this also depends on your application what is your application and all this thing. So, I am giving this 250 Hertz for now and I am importing the data. So, that no current data set will be converted to a whatever data set I will give the name I am giving the name of S1.

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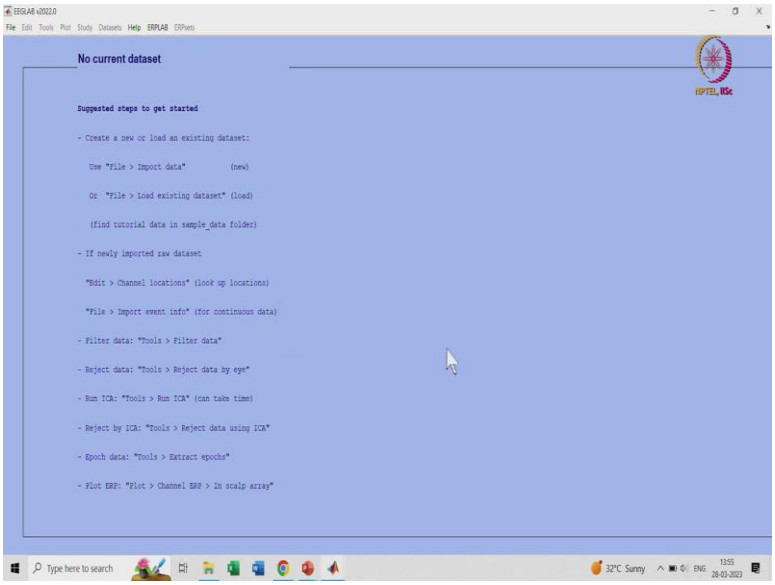

So, that is S1 also you can get all the information how many channels are there six Channel what is a frames per Epoch, epochs currently we have not entered any events and also entire thing will be converted as one Epoch.

So, that is one Epoch currently we are not added events so there are no events this is 250 Hertz when it starts when it stops if you can see total 842 second the experiment lasted around 14 minutes. You can work on that it has stored using 6.8 megabytes. So, now one by one will see as I mentioned sixth Fifth and fourth are the channel which has the event.

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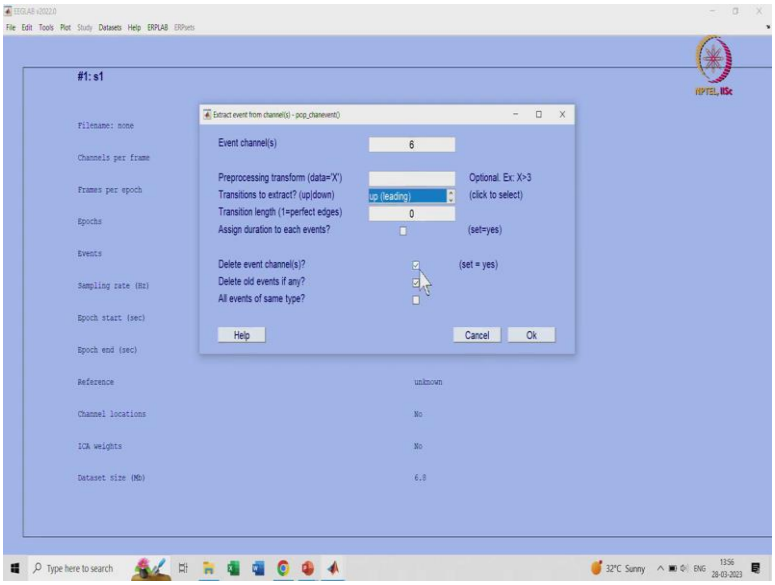

So, we after importing your particular data we need to import event as well so let us add event one by one from the data Channel because we have already given event information in terms of Channel only.

So, we are adding it from data channel here you can use the sixth Channel because as I mentioned four fifth and sixth as event one two and three has EEG data. Now, what is trigger information or event information or event and what is EEG data already covered in the previous lecture.

So, yeah this is like any previous event have been stored do you want to delete it so when you are entering your first-time event you should delete it and you do not want after that once event has been extracted you do not need the channel so that is why this both the things are checked.

Now, all events are of same time same type for six we can say but then we some more events are also there so you can keep that as it is in this extensive help is available in the website so whenever you have any question anything you can go back and check it at that point a particular point of time I am adding this particular event.

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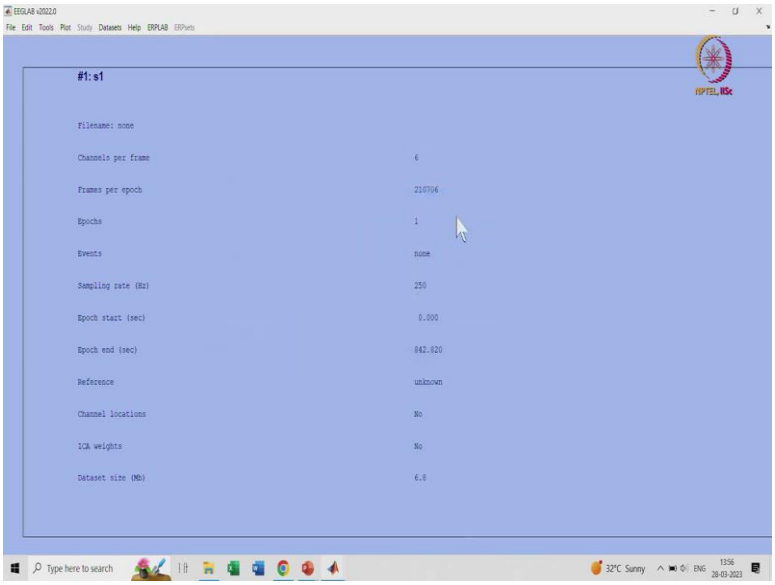

So now, this channel from frame will change to 5 because we have extracted the event information out of it and now this is five also you can see 100 events have been added. So, that sixth Channel had hundred events in between same thing will do it for fifth Channel as well.

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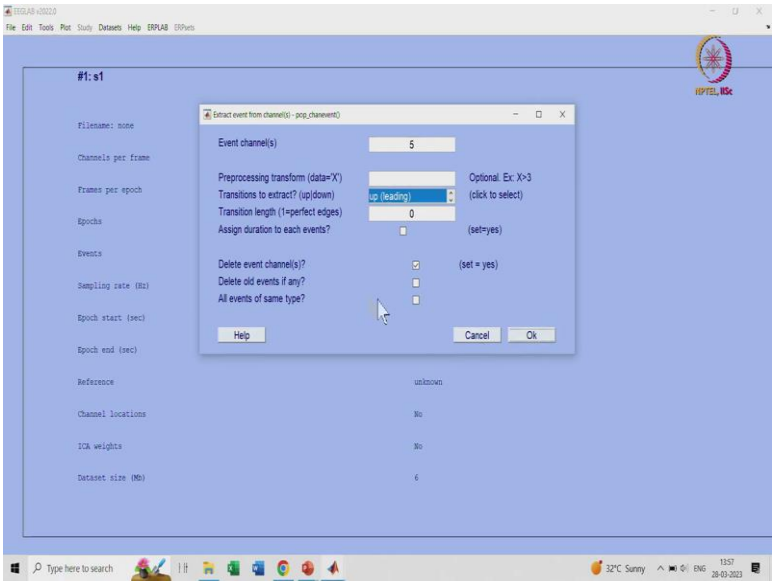

While entering the fifth Channel we need to make sure that we cannot delete old channels because we have already given information of 100 events prior. So, that we should not change that we should not check but the relative and channels we can check it. Because we

do not, we do not want that channel to remain there. We only want bio potential when the channel is extracted how we can make sure the channel accepted I will show it to you.

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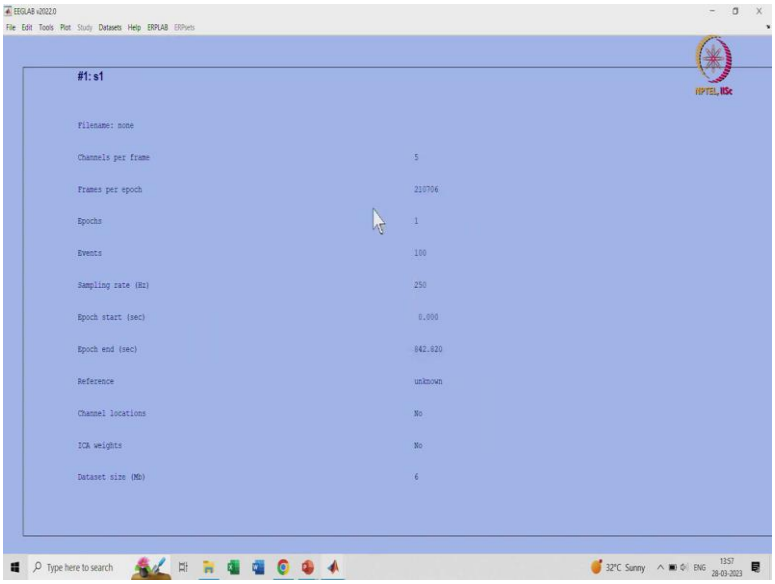

So, this is again fifth channel is extracted this has four now events has changed to 100 to 200 so both the channel has 100 100 occurrences there okay.

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Further, again for fourth Channel we have to do the same thing when you import the fourth Channel again you do not should not delete the old channels say then channel will be three and total number of events are 1000 which you can see here. So, now this event has been extracted.

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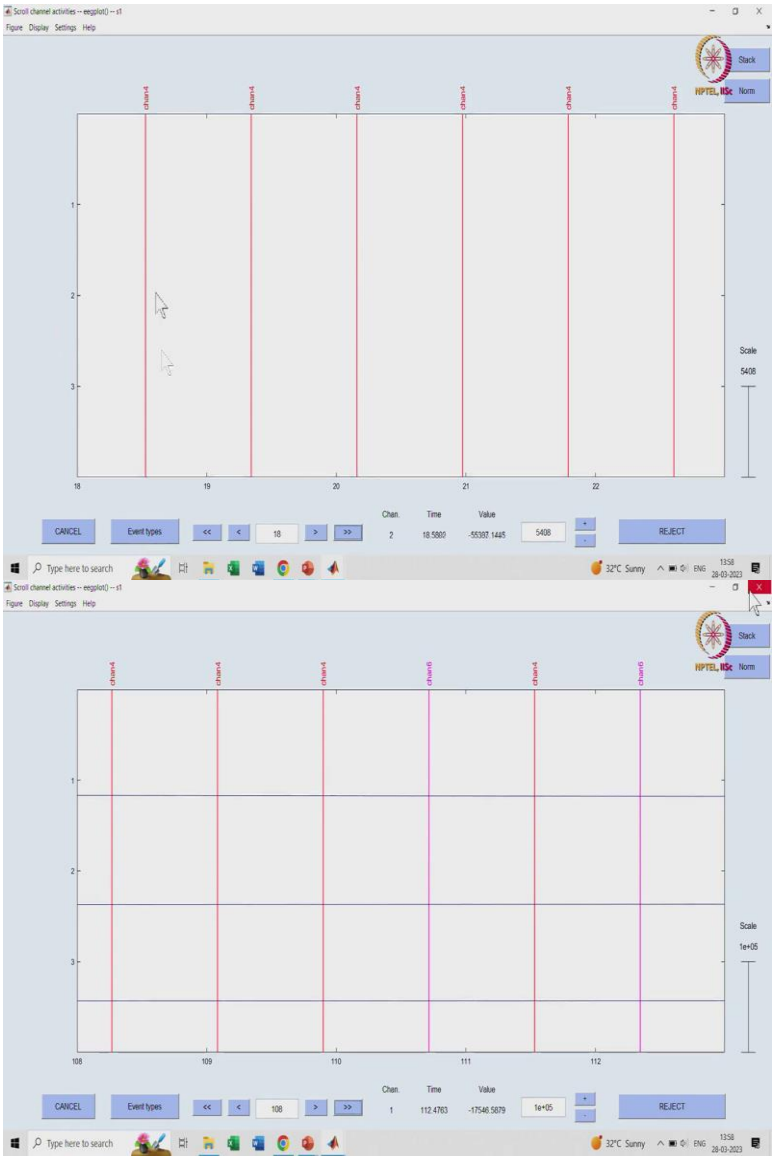

Now, if you see the data how it is looking like ultimately it is an EEG data right. So, if you scroll through you can see the channel events are there and three channels but we are not able to see the EEG channels and all that is.

Because, it is a row data it is not processed or filtered you can say it almost like a flat line now all this thing has a lot of EEG variation how will we able to extract that if you see you are not able to extract anything out of this all thing you can see is there are different event occurs Channel 4 Channel 6 whatever was there that has been extracted you can see event. But, how we can we make a neural sense out of it right.

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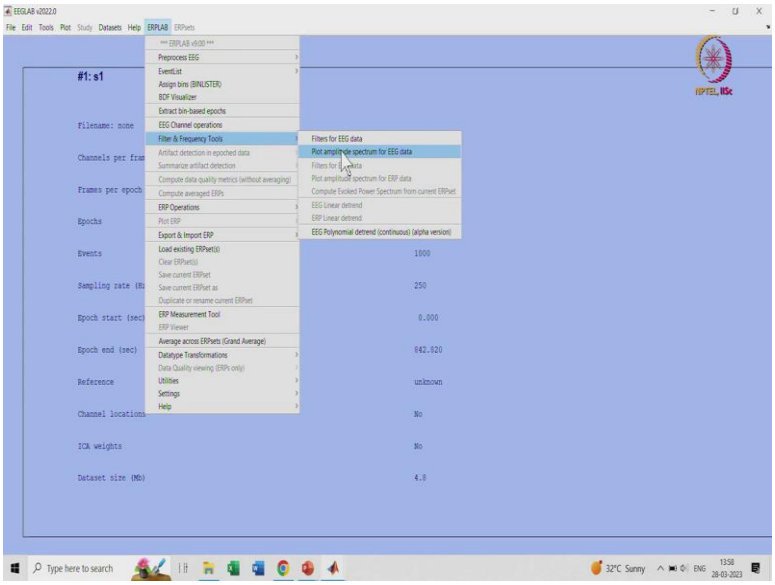

So there what you can do is you have to see that what is the current frequency spectrum that you can use a plot amplitude Spectrum from the ERP lab function. Again, ERP lab is a plug-in which should be added into the path in EEG lab which I already added how to install ERP lab as I mentioned I will put a link of my previous video in the description or comment you can go through that.

Because this is like Advanced course, I am not going too much detail or I am not informing too much basic things right. So, this I will quickly plot the amplitude Spectrum here.

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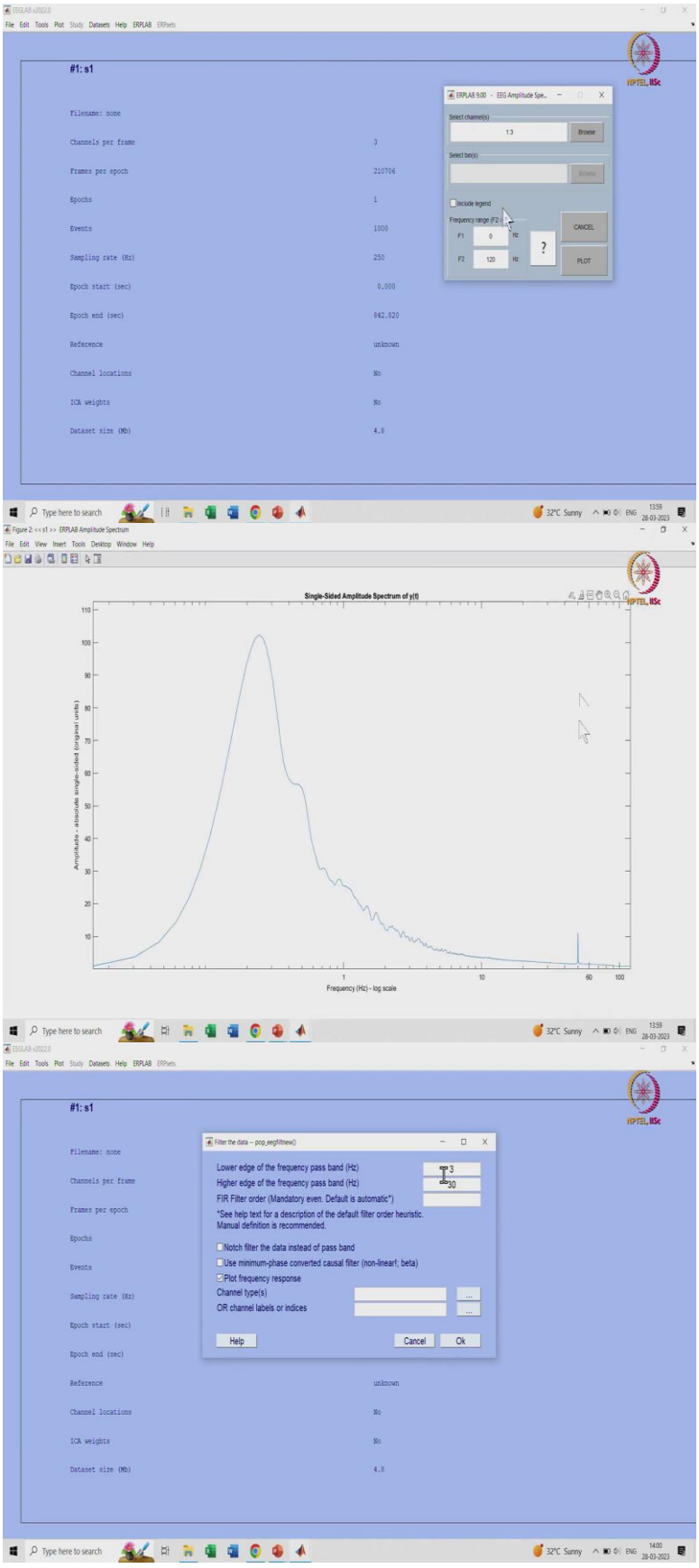

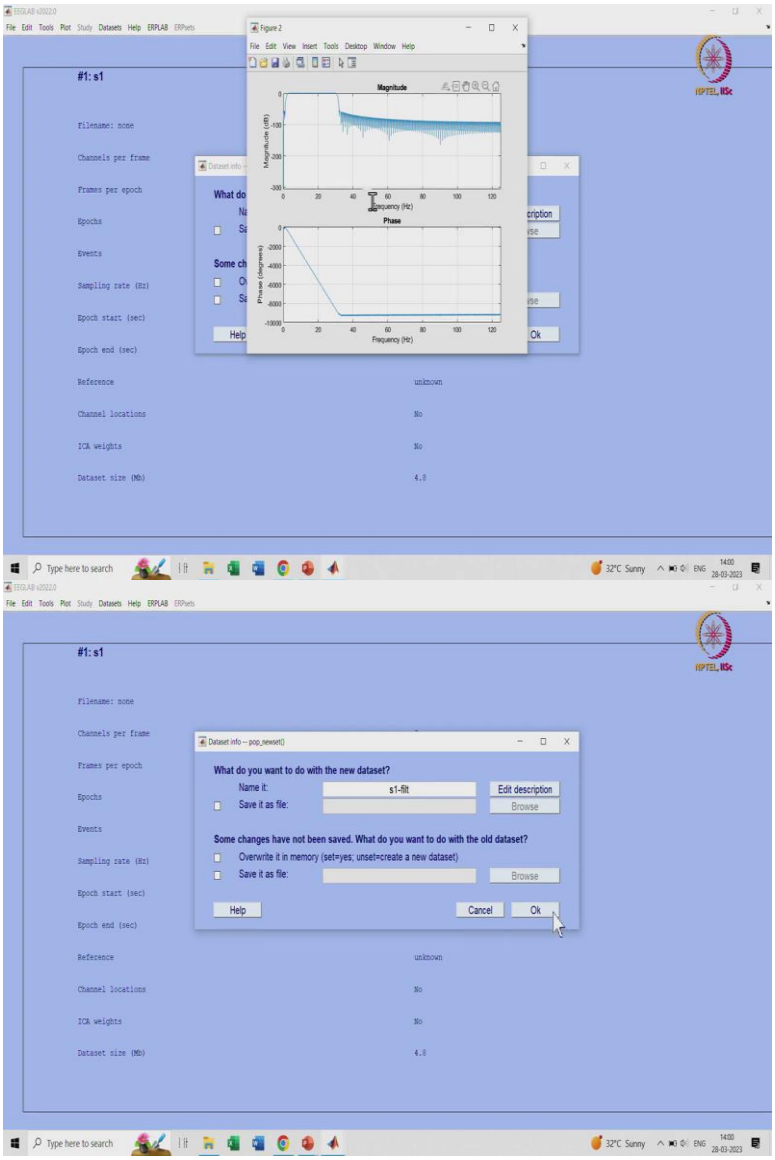

And how many channels you want to plot first three channels now what is the upper frequency 120 automatically. Why? Because your sampling rate is 250 based on Nyquist theorem what is Nyquist theorem already covered if you do not know please go through and check it what is Nyquist theorem right.

When your maximum occurring frequency is FM your sampling request should be at least greater than 2 into FM. So, let us plot the amplitude Spectrum very quickly and in amplitude Spectrum you can see there is yeah this is one of the biggest bottleneck when if you are doing neural signal processing and all.

I will show you using the data tape as well yeah 49.96 this is our main you know bottleneck which is a power and artifact how to remove that we need to put a filter. Now, two ways one is put a notch filter and remove this other one is put a filter from 3 to 30 or 0.5 to 30 and

remove it. So, we will currently put a filter from 0.5 to 30 how to put it there is a function in MATLAB tools filter the data in Easy lab basic filter.

So again, I am here there are cup you can feel free to put 1 to 30.5 to 33 to 30. For now, I am putting 3 to 30. Also, for illustration purpose I am keeping this plot frequency on so when I do that you can see amplitude spectrum and phase Spectrum also how it you know performs the filtering you can also see it is a linear phase during the range of acceptance very important if it is non-linear phase there will be a multiple issues with delay phase delay all this thing.

So, it should be linear phase also you can see in this particular range your gain is 0. Now, 0 means your signal will get 0 no that DB is 0 when DB gets 0 Log of something is 0 which is one so it will allow the signal with the gain one whereas other signals you can see is getting attenuated by at least minus 60 or minus 70 DB. Which is of a huge contrast.

So, then it will allow the signal only within this particular range. So, I will a very important naming convention once you filter it you give the name so you will have an idea that which data set because ultimately all the data set will be saved here.

So, which data set you want to go back and redo some operation first one is my original data set then it is a filter data set. So, this is now again let us see the amplitude Spectrum whether that small Spike at Power and amplitude has vanished or not.

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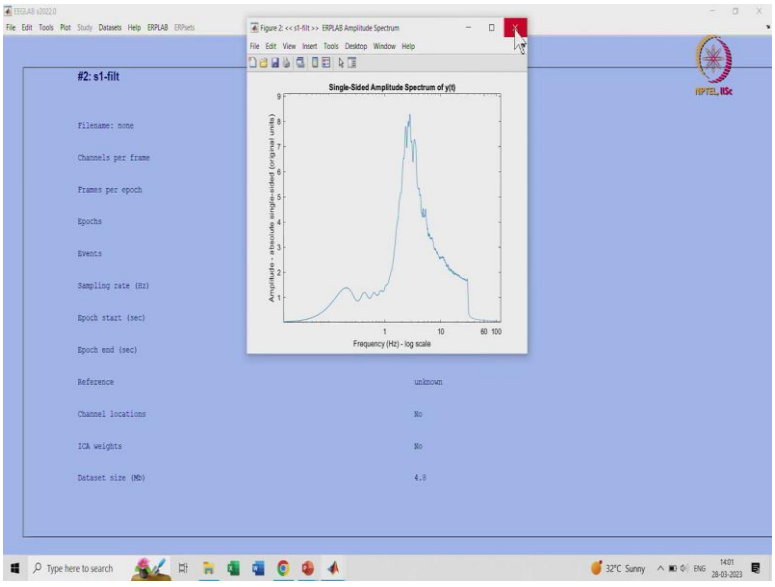

So again, I am plotting it you can see it is not there so now whatever data is there we believe you can be of a neural value. So, next step is to create an event list as per the you know block diagram what you have seen before event list can be created using ERP lab menu create (())(19:19) list and then you have to define your three events and bins.

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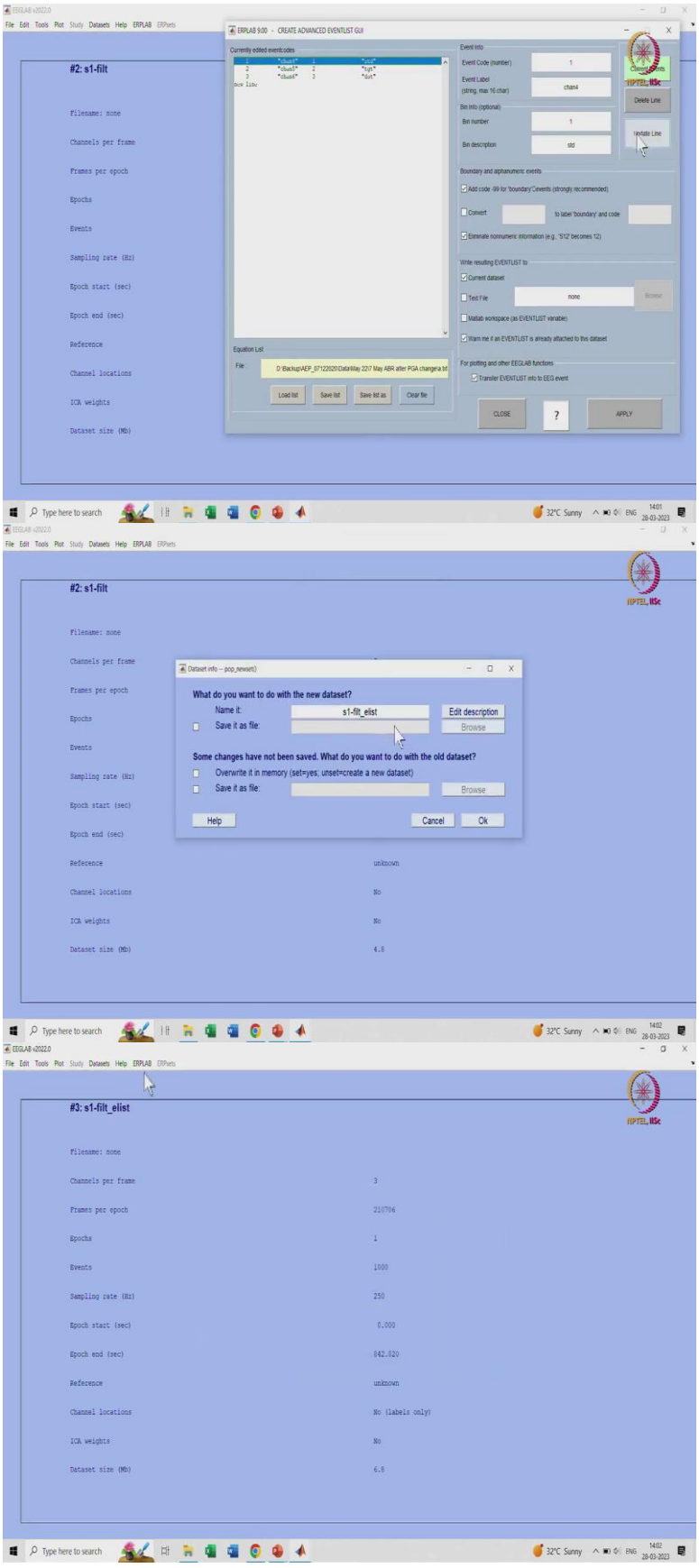

So, I already written it here the first one is event code one for Channel 4 which is my standard second one is event code two which is a channel 5 which is my Target and the last one is three channel six which is my distractor. Based on that I will be getting my values I will be getting my response. So, you have to just apply this particular thing you have to take care how to write this event information.

Once it is done they will ask do you want to code the labels so you can see yeah apply code the labels and then automatically it will be renamed with dot dash I know hyphen or you know underscore elist prefix and you will get one more data set here.

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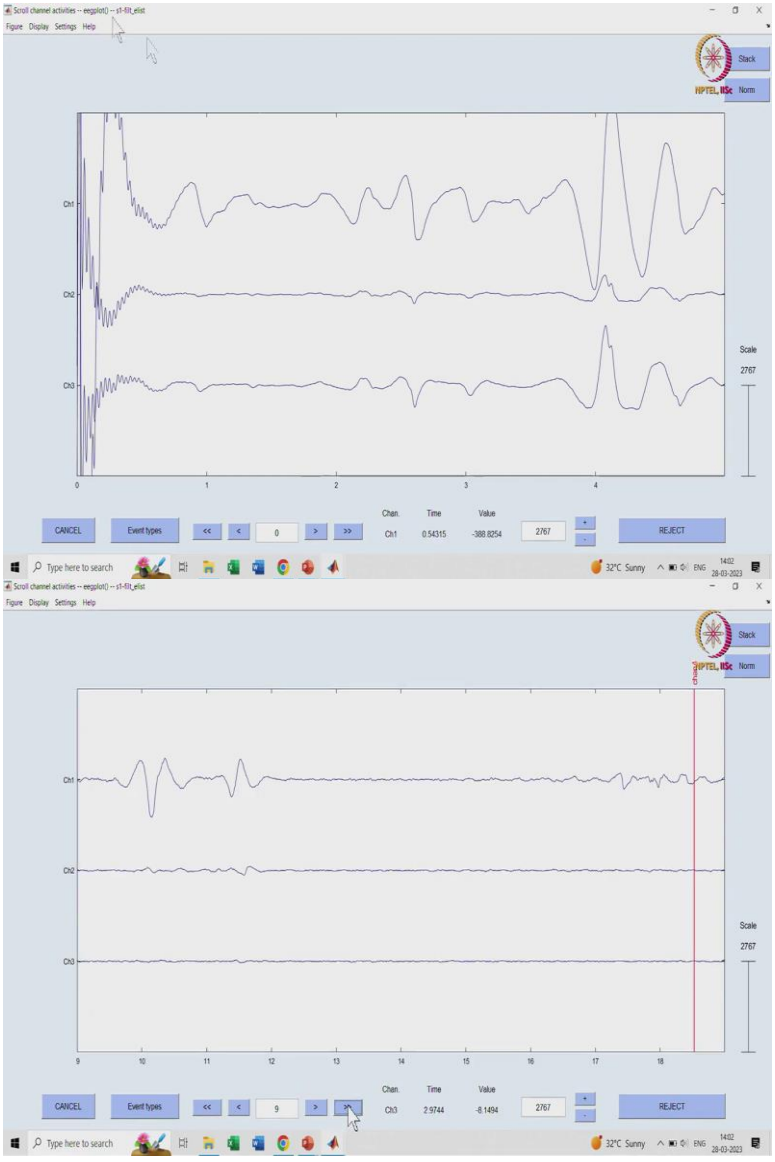

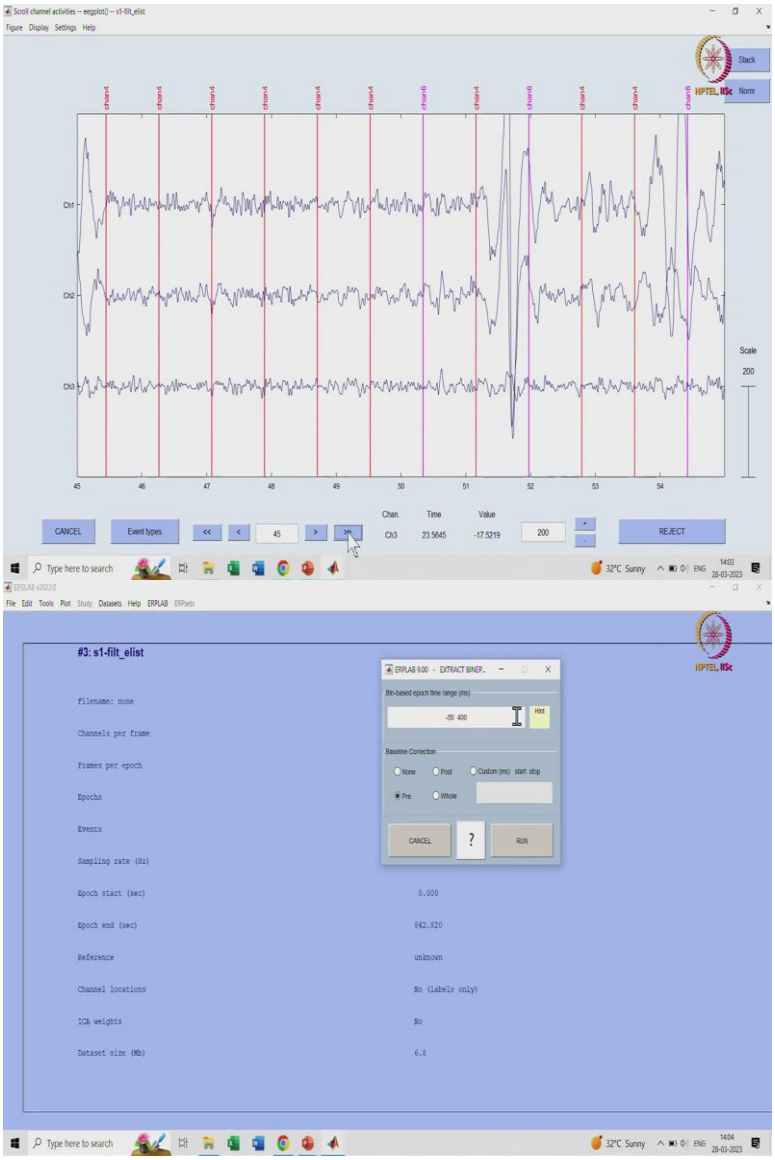

So now, you have events so let us see how much change these two things have made so earlier you are not able to see the data now you are able to see the data you can play with this time range and all this thing you see keep it here 10 this might be due to some eyeballing or some artifact that it will get rejected in artifact rejection upcoming step.

So, you can see based on the timing information and how your brain reacted to this here the scale is 2767 if you still want to see it more precise information you can go towards a smaller scale so you can see actual EEG. This actual EEG does not go beyond 500 or something scalp recorded EEG maximum 500 for the blinks and all this thing.

Otherwise, you have some movement artifact and all normal EEG you can see this all considered can be considered as a normal EEG you can hover over this and you will get a

value here this will give you a time value this will give you amplitude and this will give you which channel you are hovering like.

Let us say you are hovering here on channel number one at 68.150 for a second you are getting 0.09 micro volts. So, this again depends on what you are checking where you are checking and all this particular thing but you can see also event information is being recorded. Now, we have a good name of you know representation so we can go ahead and do some processing.

So now, we need to tell them before event consider this time after event consider this time that is called epoching very important. And you have to take minus why should we take minus time that is because when you are working on any particular EEG or ERP extraction you need to consider a baseline.

When that event occurred what happened prior to that so for that we need to consider this particular minus time interval for now I am just giving it 50 you can give it 100 also pre it is called pre-stimulus Baseline correction. But Baseline correction is important so that bin Epoch this is bin epoching stage and this also there is a pop Epoch bin function which does this particular thing.

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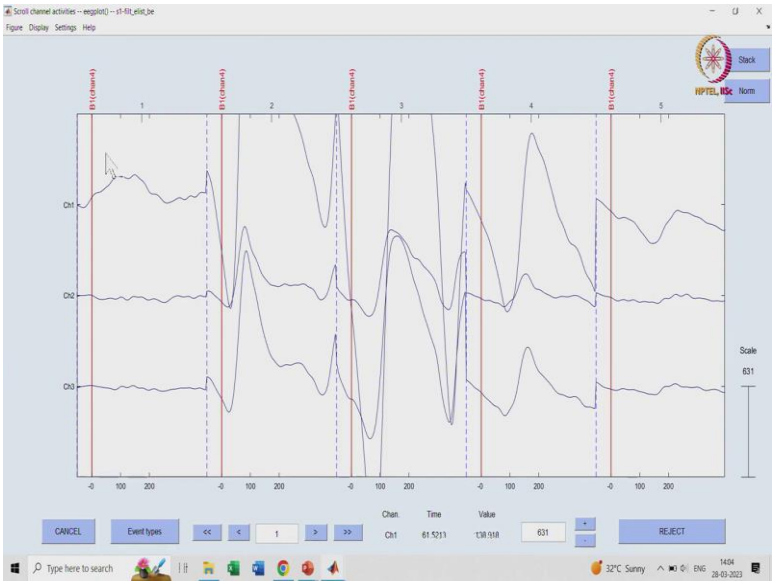

So yeah, you can run this particular thing it will generate the bin epoching and it will save as a new set so in this third data set will be replaced by four data set so you can see here this is your bin epoch. Next step is now again we will see how the data has changed at every you

can see the earlier things have gone this dashed line has come which corresponds to minus 50.

And then further it has stayed till 400 the other in between data has gone it has only saved the data which is like in the range and it is same for all channels you can see for bin four also it has Epoch verb like you know Channel 4 channel 5 everything it has been equally placed and kept.

I will there was a one instance of channel 3 as well yeah this again I will show it to you B1 is there this pink one is B3 is there and similarly B2 also we have seen before. So, same ways all bins have been epoched as per the given time range you can see it here you can verify it throughout the recording also bin 2.

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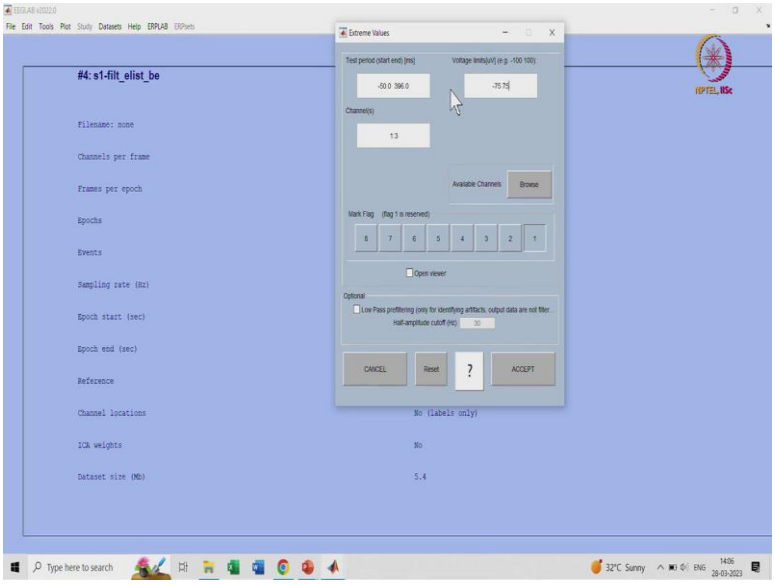

So now again let us go back and check some of the bins have values which is very high which is not neural so you can apply a simple voltage threshold and remove those bins let us we let us say we will keep the amplitude range of minus 75 to 75 this is like based on your experiment you can take any particular range and any particular as in you can take minus 52 plus 50 minus hundred to First hundred and for all three channels.

So even in one of the channels it goes above or beyond this particular limit it will discard that particular Epoch. How many epochs out of all the epochs have been discarded that you can see in MATLAB command window how we can see let us see quickly.

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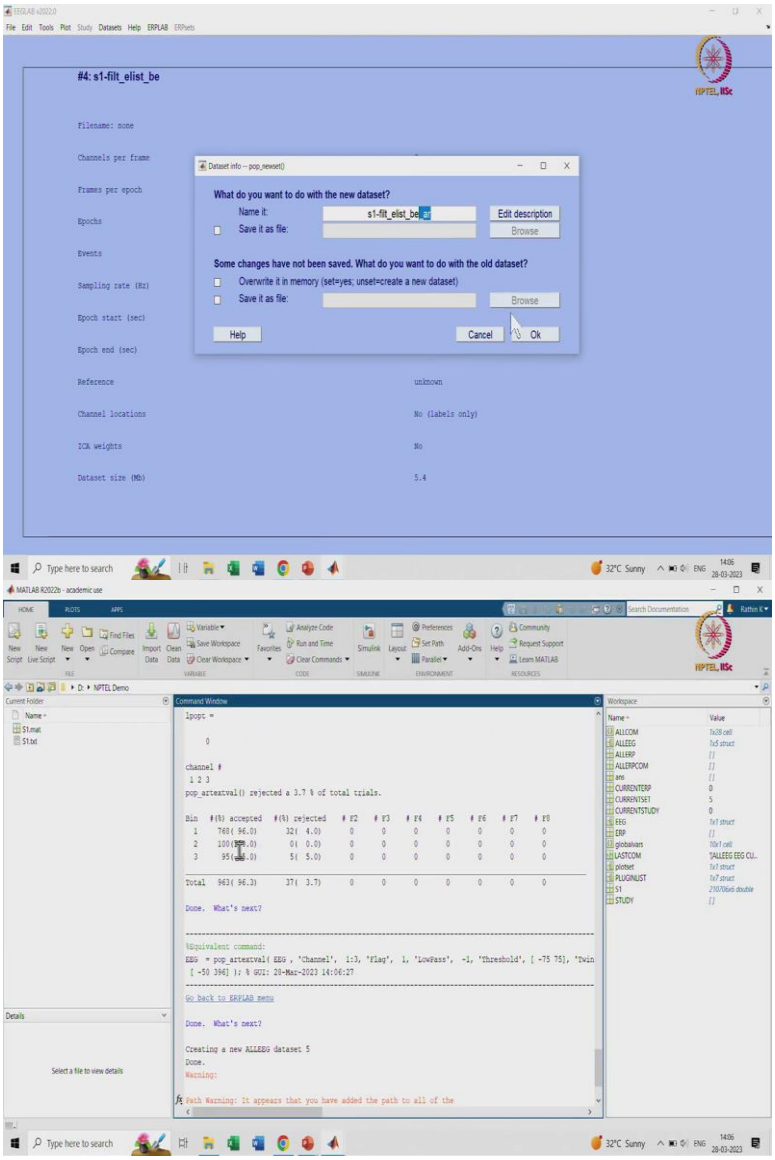

So, this is it will perform the artifact rejection and again automatically saved with dash AR prefix which you can see here so now you can you want to see how many epochs have been rejected. So, there were 3 bins first bin 768 accepted out of 800 so 96 percent accepted second bin 100 100 out of all 100 100 accepted third bin 95 accepted.

Now, I have given plus or minus 75 the total rejected trials are 37 out of 1000 and 963 were accepted if I give plus or minus 50 then there will be more rejected so that is a trade-off you have to decide there are so many parameters what should be the filter frequency what should be the epoch being Epoch range and all this thing you have to identify. After this thing your data will look even better.

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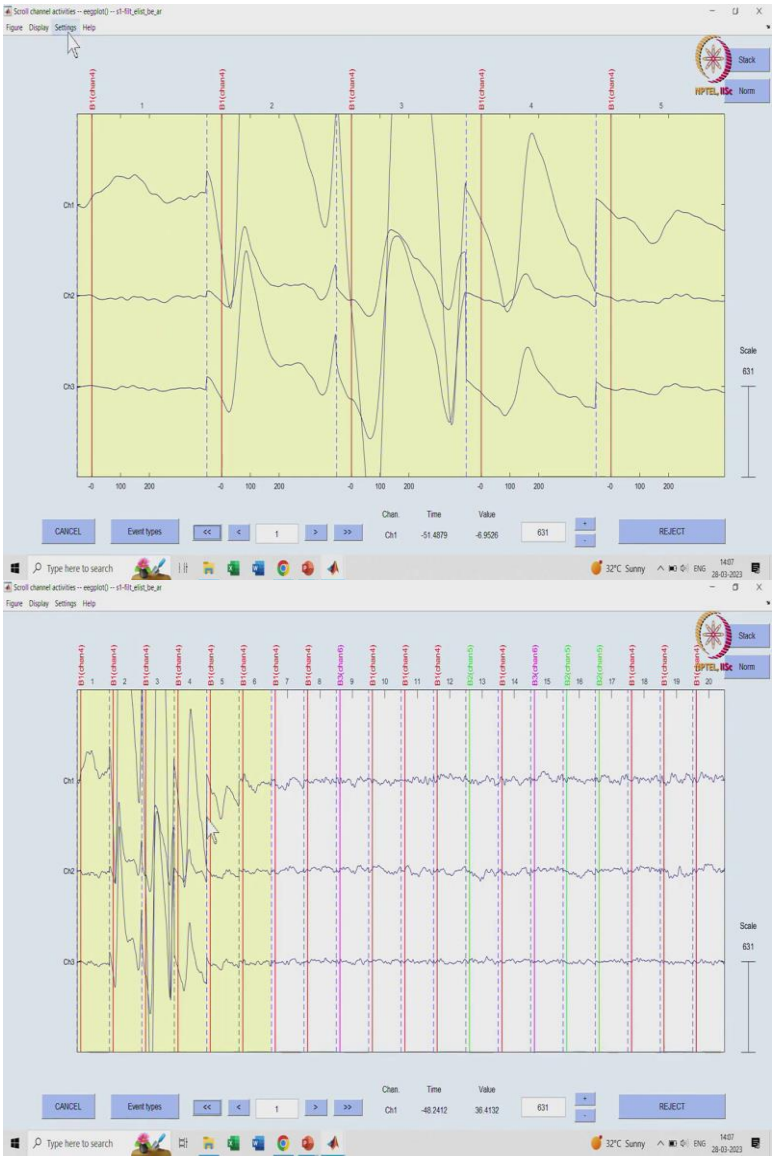

Let us quickly see the data once so initially as I mentioned some burst and all so you see those all are you know shown with this ochre yellow colour or brown colour I will show for more time range so you can see the difference between them see all this thing have been vanished.

Where this all this data or epochs have been accepted whenever it goes beyond some non neural range it will be discarded like this. So, yeah again one small illustration it is happening and you know artifact rejection has been one formed you can check it there will be like thousand epochs and out of this 32 have been rejected.

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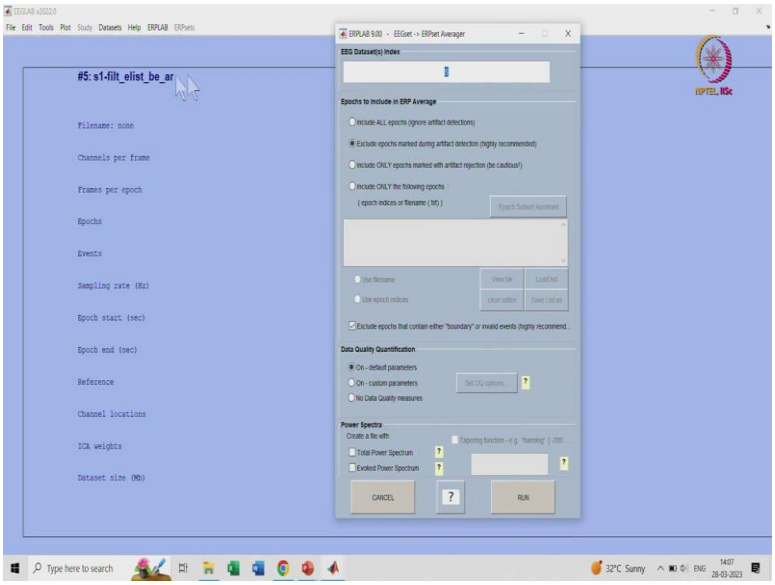

Last step is to generate a computed average ERPs so that will be saved as a final this you can select which data set you want to average here again what are your parameters and all you have to exclude epoch's Mark during artifact rejection. So, this is important you should not include all the epochs because you have identified that which particular epochs having non neural High amplitude so that you can remove and again you run it.

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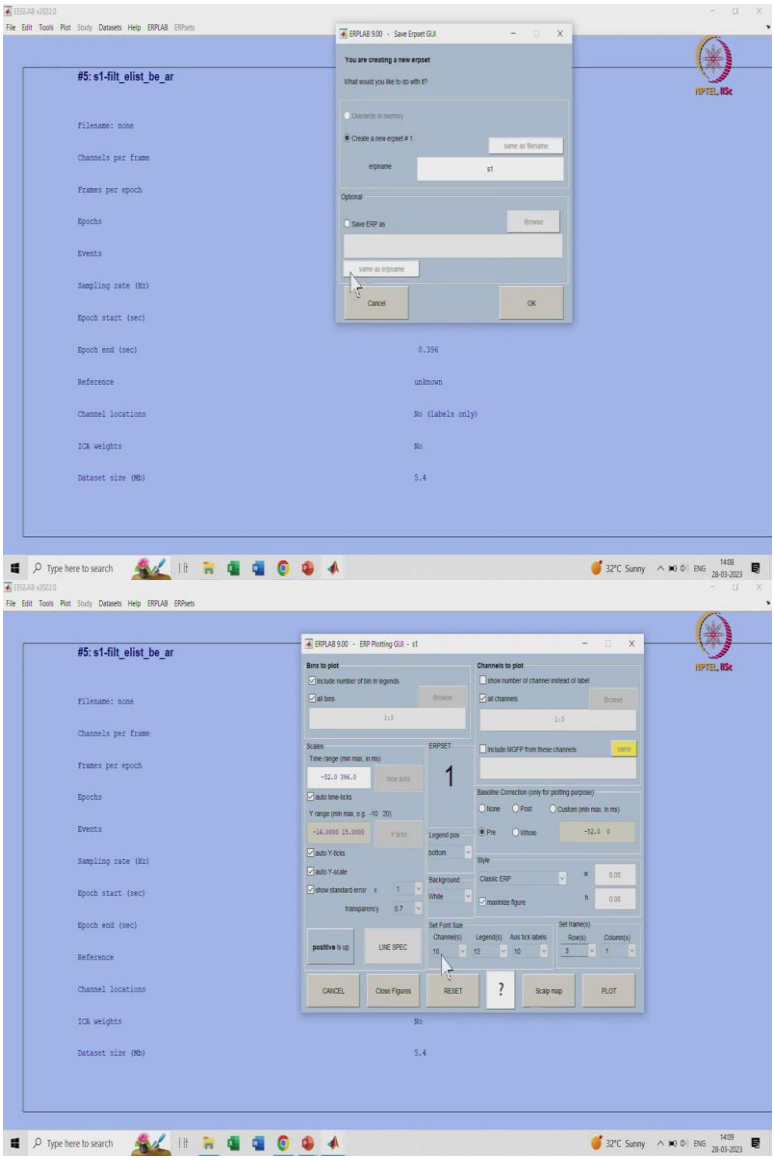

Once you run it it will generate, and something called ERP you can save it as S1 so it will store value in ERP. ERP is one structure which shows how many channels are there how many bins are there what is the data what is the time range etcetera.

So now in ERP set there will be one ERP data set has all the performance operations which we have performed S1 field at least bin Epoch artifact rejection and then here ARP how it looks like what are the waveforms. So, we can quickly see that using plot ERP waveform. When you open the plot ERP waveform there are several things you want to plot all bins all bins means standard Target restrictor all channels means there are three channels you want to plot all three channels again you want to scale Auto you know Y axis you want to show SCM.

SCM is very important thing once it really you know appears I will tell you it is shows the variability how many rows you want how many columns you want all this thing you can tweak it and make the things you know your format you can change it make your event more make your results more publishable.

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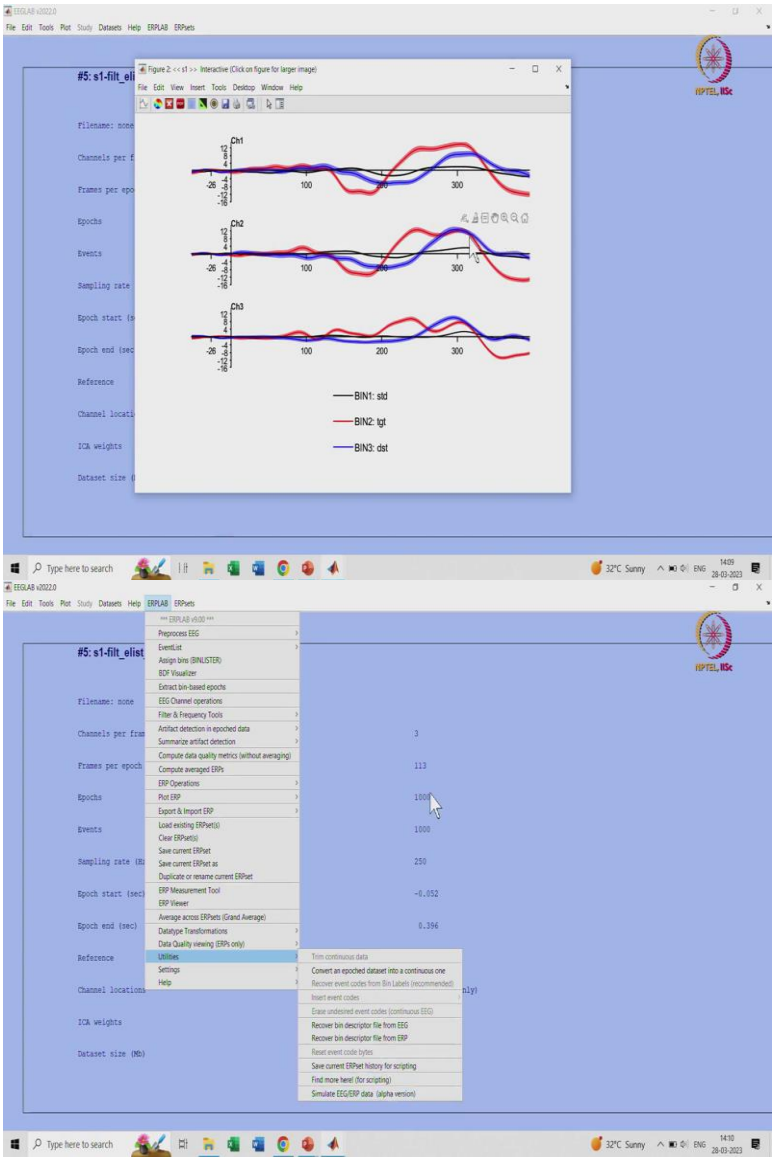

So, these are your final result I mentioned this is about P 300 right. So, if you can see it around 300 millisecond there is blue line and red line Peaks 300 means not exactly 300 it should Peak but somewhere in between you know 250 to 400 200 to 400 that is a peak and compared to this black line black line is very hardly visible here but that is your standard.

So, whenever this rare event comes your brain reacted to that and you are getting this kind of response so this is you know the overall idea you have to you can see there is like here it is a

Time axis, and it is a millisecond this is your amplitude and minus 50 to 400 it has been plot and SCMs are also separable.

SCM means standard of mean during thousands of trials how much the variation occurred. So, in between this and this SCMs are also separable also when it comes to target the response is much spread out compared to the response for distractor. Again, you can play with this you can identify what should have happened in between this example also for that you can check your Imaging ERP Imaging.

So, there are tools for that as well you can check it also one more thing is you can have a utilities and you can generate your own data using utility assimilate EEG ERP Alpha version is there so for different things how many channels data you want. And if you do not have your own data there are many students who have asked me that we do not have a provision to record EEG how can we learn this thing.

So, first thing is there are online data sets available second thing is there are many conferences which gives you data and opportunity to you know do several signal processing algorithms on that and you can you know trust the data set an extra stable data set which you can play with and learn so many things. Apart from that you can simulate your data from here and get the things done EEG lab is a free software you can install it with your MATLAB. So, this is like a brief overview.

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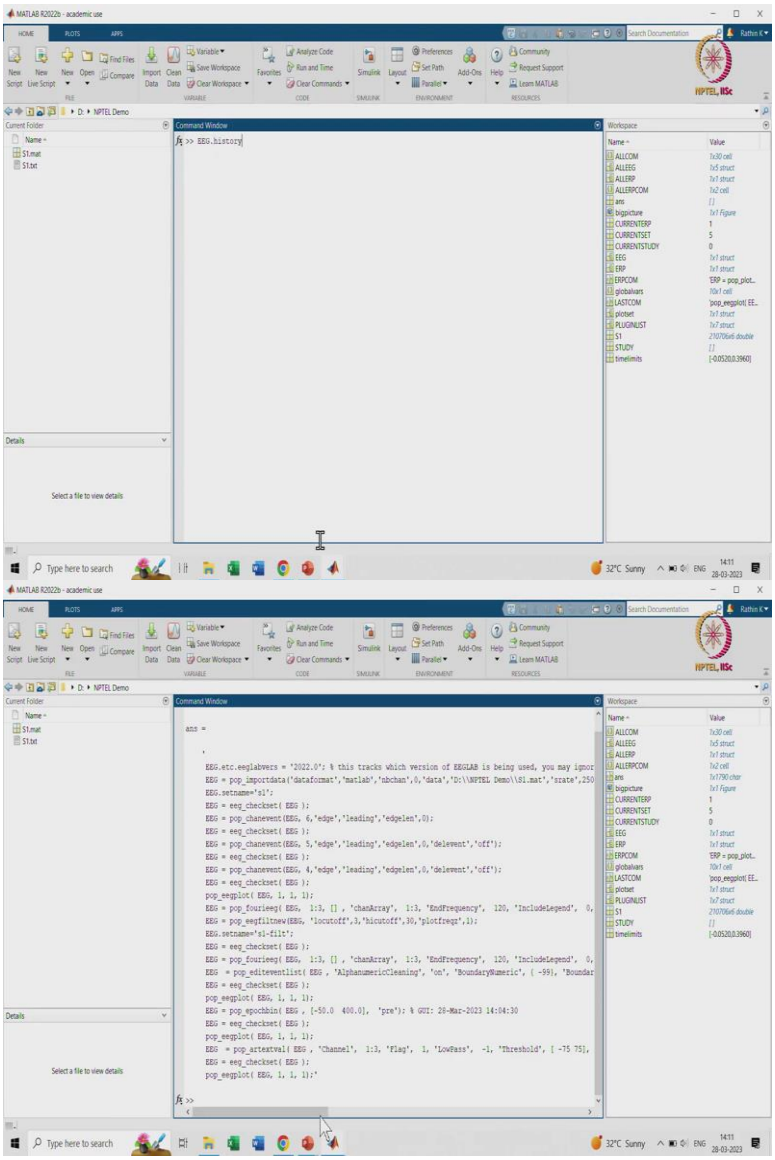

Another point is supposed you have some data and all you can explore different commands in MATLAB one more thing I wanted to tell you before I finish this lecture is you write EEG dot history.

Whatever operation we have done it will come as a command line interface, so this is for one file. Now, by just one normal, normal communication or you know batch file processing code you can do the same operation for all the files and you can run a code so you can just you know run the code go for lunch and come back by the time all the recordings would be ready all the results would be ready which should be sent to a doctor or neurologist.

So, yeah that whatever we have done here in terms of your processing same thing can be done using Code as well so GUI and code mapping for higher number of subjects this batch file processing is important otherwise you can go ahead and do the same thing whatever I have done with using GUI.

So this is a brief overview if you want to use MATLAB for some other applications also there are multiple apps based on your you know different problems considering this neural course there are neural Nets and all this clustering all the classification machine learning and also corresponding on ramps are also available.

So, you can just check it whenever you have free also there are plethora of signal processing applications are there which you can play with not only for neural engineering for overall biomedical engineering and also for you know your normal solving problem here you can see image processing right.

There are so many problems of email processing and computer vision as well which you can learn it and go into as much digital as you want. So, again it is a sea you can you know swim by yourself as much as you can the objective of this particular small quick module to identify or to you know make you enable that how we can do all this thing what is EEG lab what is ERP lab.

It is very important if some small computation or something which will be you know asked in some assignment or question exam or something you should not be feel alienated what this is so yeah that is the overall idea. So, I hope you have understood all this thing properly if you have any doubts, you feel free to write me write to me in the Forum or you can reach out to me using this email ID. I will probably meet you in some other course for some other module till then if you have any question as I mentioned feel free to write to us and all of you please take care, bye.