Advanced Neural Science for Engineers
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Lecture 37
Basics of EEG/ ERP Experimental Design

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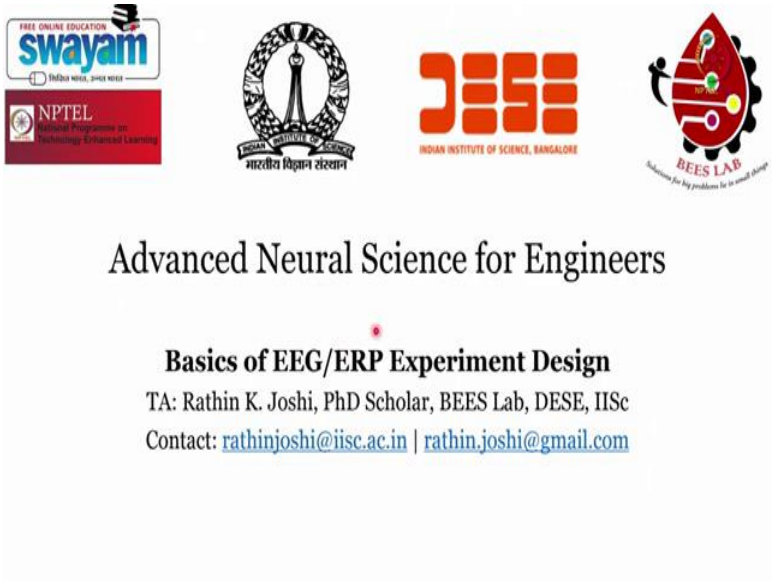

Hello everyone. Welcome to the course Advanced Neural Science for Engineers. Welcome to this particular TA class, which is on Basics of EEG and ERP Experimental Design. Here we will see the fundamental building blocks required to conduct an ERP based experiment. What is ERP? How it is different from EEG? Whether it is same as EEG or not? Everything we will see in this particular lecture.

So before moving to the fundamental building blocks of that, let me quickly show you, what is ERP and where it can be used and all these things.

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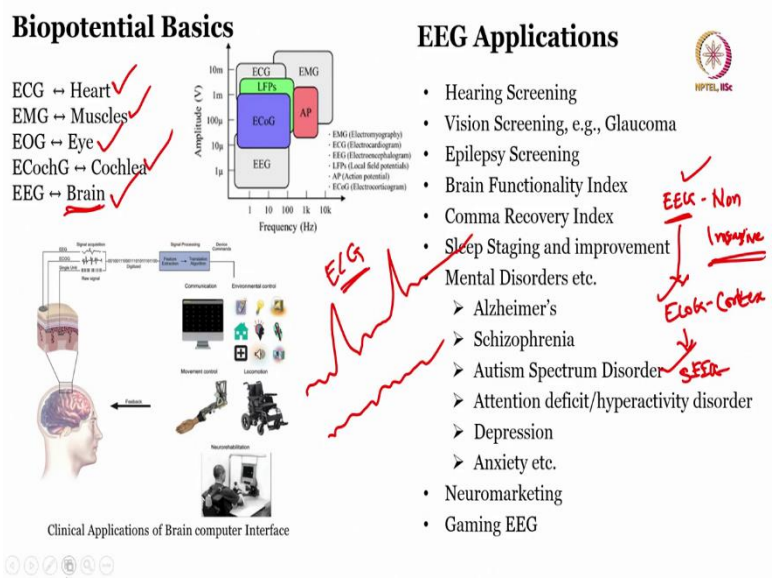

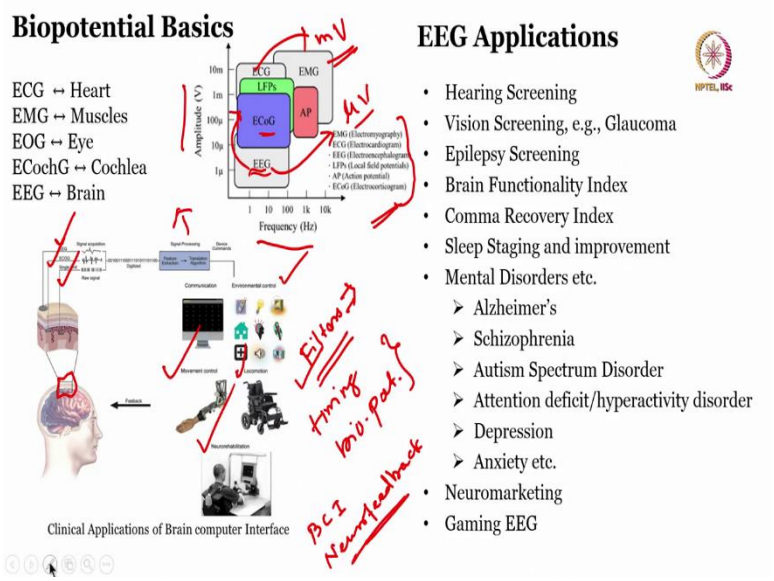

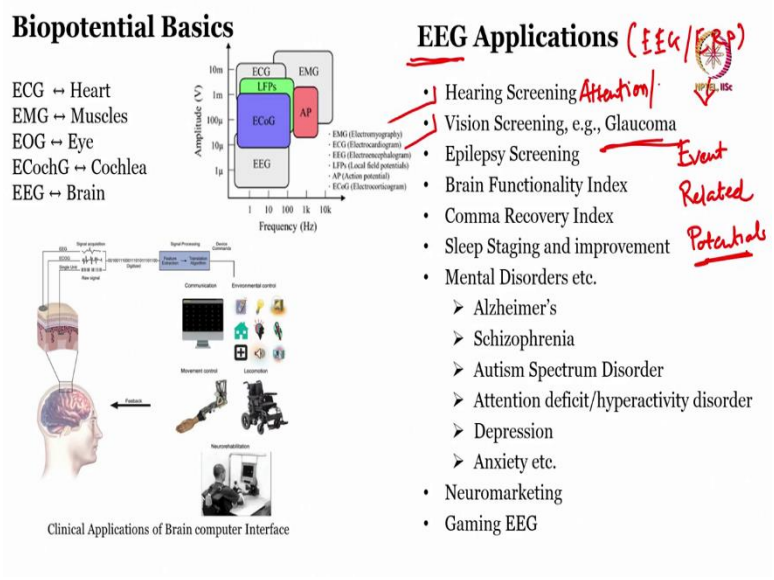

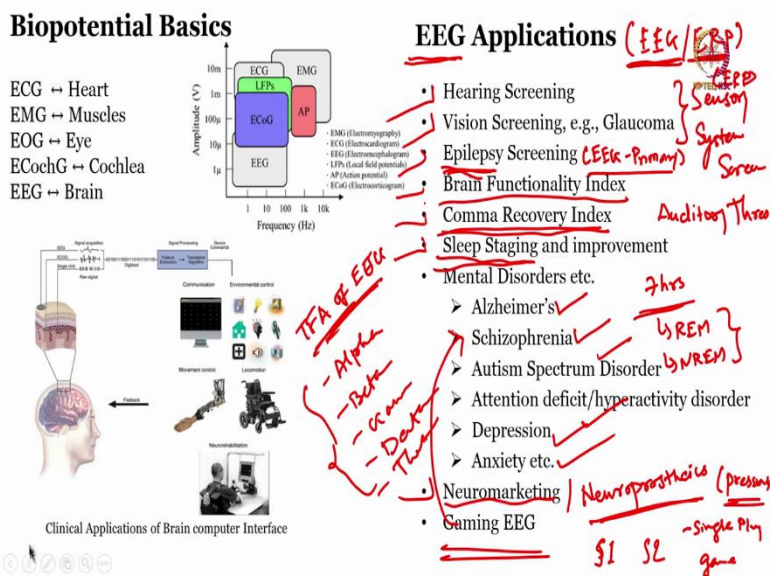

So this is like an overall fundamental overview of the biopotentials. As you all know, it starts with all the biopotentials like ECG, EEG, EMG, ECochG, and all these things you would have seen, ECG in many of the movies or even in your day-to-day life, you would have seen that this kind of repetitive electrical discharges, Electrocardiogram. Which is mainly related to, and which is providing the health status of your heart.

Like this, if it is recording from brain, it is something called EEG. EEG, electroencephalogram. If it is recorded from your cochlea, there is something called ECochG, and then ECOG. ECOG is electrocorticography. ECochG is electrocochleography. So based on your application and what you want to measure, there are different aspects of recording this biopotential. So like, as I mentioned, ECG for heart, EMG, eye for EOG, and then EEG for brain, and again, ECochG for cochlea.

For brain, concentrating the scope of this particular subject we will more focus on brain. So EEG, EEG is non-invasive measure, non-invasive. Means you do not need to do any form of surgery or any form of cut on your body to perform this particular thing. When you go one level down, there is something called ECoG. And then there is something called SEEG Stereo-EEG. ECoG as name suggested, ECoG, it is taken from your cortex. Whereas this thing is stereo-EEG, which is even in the depth of your brain.

When to do EEG, ECoG, and SEEG we have already seen in one of the class. So this is like an overall identification of biopotential. Here you can see the different form of biopotential has been summarized when it comes to the frequency and amplitude. EEG having the lowest of amplitude. When you go from EEG to ECoG, your amplitude increases as we discussed, and

you will get it over certain more frequency as well. LFP is also there. ECG is there, ECG is in terms of few millivolts, whereas EEG is in terms of few microvolts.

If ECG, EEG is in few millivolts, you have some abnormal discharges or something you should consult your neurologist or something. So like this is overall idea about the different biopotentials, which is being used in the practice and time frequency you know, amplitude, frequency, and all this characterization of that. Also, you can also put one more access to this and check about the invasivity, which is more invasive, which is more complex. All this thing you can identify.

Here, it is a very nice illustration that if it is recorded, let us consider only this much part which is shown here. It is taken from one of the very nice paper. If it is taken from here, you see that this is EEG. If you go in the cortex, this is ECoG. And then you can even measure a single unit activity, which is like current state of the heart research deals with in terms of neuroscience.

Once you acquire all the signals, it will be digitized and signal process, there are much more intermediate steps as well. And you can use them for several things for locomotion, for moment control, for neurorehabilitation and all this thing. Basically, in a nutshell, your EEG would be recorded and then it will be processed, and when it comes to processing, what you will do? So when it comes to processing, you should know that what type of your signatures you are looking for.

You can apply those filters. If it is pre-running EEG, applying filter should give you some response. If it is event-based experiment, like ERP experiment or something, at that time, you should take timing information. You should also take the biopotential. All this thing you combine generate, see where the event is occurring, and then there also, you can apply filters, then average it out and find out something.

All this thing is being done on neuropotentials to make a neural sense out of it. To get a footprint of your brain activity or brain waves, whatever is happening. Using that you can check or moderate some of the other parameters, like as you mentioned, environmental control and all this thing. This is like a BCI interface, or you can say that neuropotential based or neurofeedback rather.

Because you are considering some form of EEG signatures and then changing something. So these are like some of the basic things which you can do an illustration for a brain computer

interface, which is very important. So what we can do with this, there is a plethora of application. If you just record EEG, if you have a provision to record EEG and timing information, so which makes it EEG slash ERP.

Application is not only for EEG, this all application, whatever is listed here, it is for ERP also. What is ERP? ERP is nothing but Event Related Potential. We will see in detail what I mean by event related potential, but these are the some of the known application. It can be used for hearing screening. It can also be used for vision screening for disease like glaucoma and all. With this you can also identify something called this is hearing screening, this is visual screening. So you can identify something called attention.

Currently, I am explaining few things to you, right? You are listening to it, but whether you are attentive or not. So if you have an EEG headband, and when I am speaking, if you are acquiring that information, processing in your brain, there should be certain signatures. Attention, working memory, all these kind of things you can identify using EEG and ERP. This basically comes under the broader umbrella of sensory system screening. Both the things.

I will quickly write there, so it would be more relevant. Attention and working memory is fine. Already know about this event related potential and all. So these two things comes under sensory system screening. And both of them are application of ERPs, no new potentials or event-related potentials.

Then epilepsy screening. Primary method for epilepsy diagnosis or something is your EEG. Primary, non-invasive. If you have any of the history or some kind of episodes or have issue with neural disorders, EEG test would be the most primary and, first thing which doctors suggest. Because if it comes in that, if the disease can be identified by clubbing the EEG with syndrome, it would be one of the first measure and you do not have to go for any kind of neurosurgery and all, et cetera.

We mentioned about the sensory system screening, also attention working memory. You can add some more parameters and you can also identify brain functionality index. How much your brain is actually functioning or what is the, this all vision and hearing it can be quantified as well. You can identify something called auditory threshold. Everyone has their own auditory threshold. Below which they are not able to perceive or hear the sound. So this all comes under brain functionality index.

Also, another important aspect is coma recovery. Now, you have some of your, any of known person in coma there is no particular, coma is a state of brain dead, so how likely that person to come out of coma. So you can identify that thing by doing some experiments and designing a particular stimuli and all this thing.

One another major important application is sleep staging. Generally, for any human being one third of their life, they sleep, and it is very, very, very required. To reset your brain, to get the proper mental ability and health at least seven hours, six to seven hours sleep is advisable. So you can identify.

But during those seven hours of sleep, there is a cycle in that particular sleep. How many hours you are in REM sleep? Rapid eye movement. How many hours you are in NREM sleep? So all this thing you need to identify, how you will identify? By doing time frequency analysis as write off EEG. There are known bands, Alpha, Beta, Gamma, Delta, Theta.

So each and every band has their own frequency, and there is a flow from which, when you go into the sleep and you come out of sleep, there is a known progression of these frequency bands. So the activation of this band, activation and transition of this band will tell us that exactly how qualitative sleep you had. So this is also one another application of EEG, ERP, et cetera.

Further there are applications in the field of Alzheimer's screening, Schizophrenia screening, ASD, ADHD, depression, anxiety. All these things can be screened or identified or quantified by using EEG. Of course, there are some other aspects as well, there is something called neuromarketing and neuroprosthetics. In your sensory pathway, some things are not present or working correctly. How can you embed some additional thing to make the person complete that sensory system loop and make him do the things like it should be.

Another time is neuromarketing. When you are scrolling through Amazon or any of your websites or e-commerce website or something, whether you like particular thing or not. So this is like another niche area, which is still people are working on, and it is a intersection of commercial aspects with neurological aspect. So again, this is also another important point to make.

Further, there is something called gaming EEG. Now, this again is related to Schizophrenia or some other disorder. You have two persons, one having Schizophrenia, one is not having

Schizophrenia. You make one single player game. Most of you would have played video games and all, I believe. So single player game, and you ask that particular character to kill a certain amount of enemies.

So that person with Schizophrenia might end up killing more. And also, you can embed the pressure using which it is hitting a particular button on your remote or your keyboard. So all these things are possible combinations for BCIs and currently used in practice and everything can be done just by using EEG. Or if required ERP. ERP is like EEG only, repetitive time logged EEG events. I will come to that in a short while. So just wanted to give an idea about all this thing. So let us move ahead and see further next slide.

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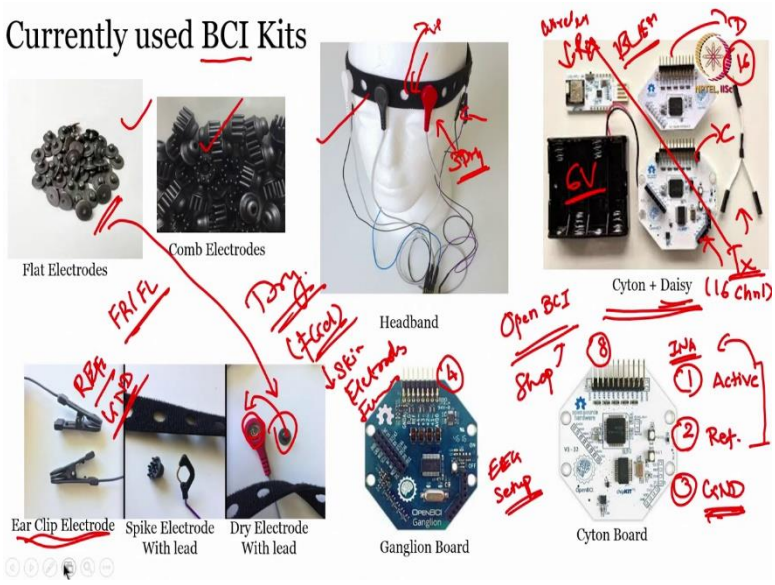

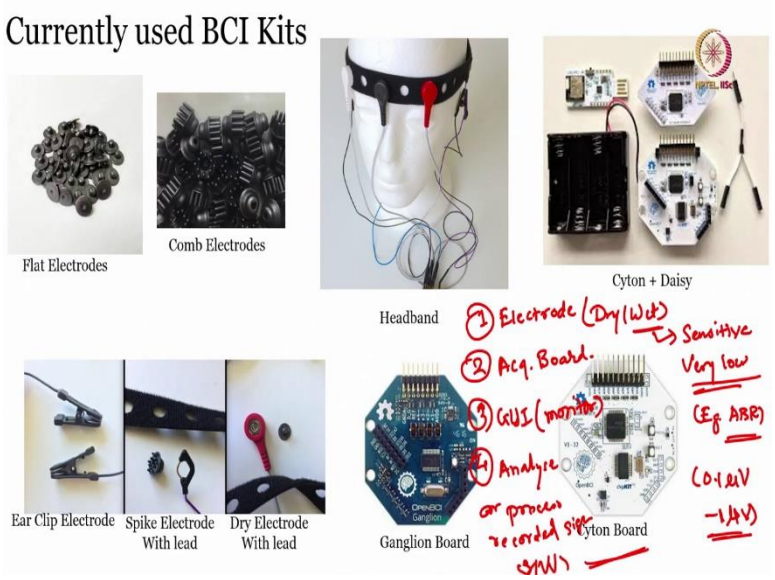

These are the known BCI kits. How can we record EEG? There are so many applications, how can we reach to that particular level? So these are some of the companies. And come up with different kind of electrodes. So this is like flat snap electrode or flat electrode. There is company called FRI, Florida Research Instrument. They comes up with their own sets of electrodes.

There is one more company called OpenBCI. Those boards you can see acquisition board here, you can see Cyton plus Daisy. Cyton plus Daisy is 16 channel board, and Daisy can be stacked. This is Daisy and this is Cyton. So this can be stacked on this and you can use this kind of splitter if you want to use a common reference between them. It is operatable with 6-volt battery, 1.5-volt battery.

And here, this is particular dongle. So this is wireless receiver unit. This OpenBCI Cyton Daisy board has a transmitter inside, they will communicate with this thing using BLE module, Bluetooth Low Energy module. You can go ahead and read more about this kind of thing in OpenBCI website. There are different products. You can also go to shop of this particular website.

This agenda for telling all this thing to you is to have an idea that if you want to realize some brain computer interface, how do you do that? What are the acquisition device you will use? What are the electrode you will use? How will you put it?

So if you see here, person is wearing 3 dry electrodes. Again, when I say this electrode, this is again flat snap and comb electrode, this electrode. This all, one, two, and three, all electrodes are dry electrode. What is dry electrode? It does not require any kind of gel. Gel is not required to prepare a subject. Sometimes to maintain or reduce the skin-electrode impedance, gels have been used.

Here in this case, it is not the case, it is not required. You can see a mannequin with 3 dry electrodes and a very simplistic headband. You can wear it and just take the recordings. Provided you have proper reference in ground. For any kind of EEG or biopotential acquisition, you required three things. One is active electrode. Second one is reference electrode, and third one is ground electrode.

Difference between active and reference electrode will be given to instrumentation amplifier, which will further amplify, and you will get the recordings, and all. Ground should be common.

So this three electrodes have been used. And using this you can have a different montages and all. I will come to that. So this is like an overview. Again, this is 16 channel. This Cyton is only 8 channel. This is ganglion that is 4 channel. Based on your application, you can use or select a different amount of device.

This, again, this is the same electrode there are many electrode, you can see one here, which has a trench in this holder. So this electrode sits here very properly. You can take recording with this kind of bands once you put this electrode inside that. These electrodes, which you can see here. That is generally on the ear clips. That is why it is known as ear clip electrode, which you can see here.

And that is generally used as a reference and ground in most of the neuro applications. Easy to put it on the ear lobes. So these are like overall kits and ideas about if you want to have your own EEG setup. What and all you require? So if I just think about experimental point of view. First of all, you require electrode. Let me just erase everything, so we can have a list of that.

If you want to record or have your EEG setup, first thing you should have is electrode. Again, when you say electrode, you should know whether you want dry electrode or wet electrode. For dry electrode, you just have to wear it and it will work. Wet electrode you have to prepare a subject, but for some of the applications where your area or your target value is very sensitive or very low.

For that wet electrode is advisable. One of the example, there is something called ABR, auditory brainstem response. I would like you to explore from your, what is this? But their ranges 0.1 microvolt to 1 microvolt. So for this, people still use wet electrode with gel. Which is advisable. So yeah, this is like overall idea about the electrodes.

Then what else you need? You need acquisition board, very important. How you are going to record it? Once it is acquired, you should also know where you are going to get the recorded file and if you want to see your recordings, then GUI is required. OpenBCI has their own GUI. So the GUI is required to monitor the biopotential.

Then what else is required? You require some software to compute. So analyse or process recorded signal. That is like software. Of course, you require laptop or some system to see that. So this is like what are the currently used BCI kits. If you are planning for any experiment, how you can do that in a nutshell.

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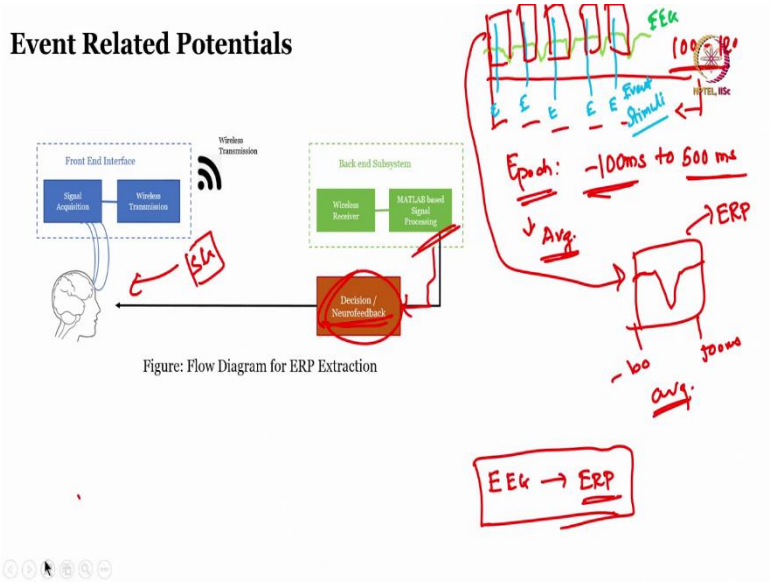

So let us quickly see the next aspect, what is event related potential? As I mentioned, this is very, very simplistic picture of that. Let us say we want to record event related potential, some kind of sound or something. So this is your normal EEG waveform, which is being recorded in response to some of the image being shown or sound is being presented. So let us say you are getting this kind of waveform.

Now also we are providing some of the, as I mentioned, some image is being shown or consider that some sound is being presented. So that happens exactly at this time, at regular time interval, but like this. So this is your event. E is nothing but your event. Green is your EEG, which is being recorded.

So what happens is when you present one particular event for multiple amount of times, your brain reacts to it specifically. So what I wanted to say is each time after this presentation, you record for some amount of time. Same goes for here, same goes for here. Like this if you do, you are repetitively recording EEG for certain amount of time called epoch. It is your area of interest. Let us say I want to record it before 100 millisecond to after 500 millisecond. This is just to give you an example.

Why before? So I just want to know before event occurred, what was the baseline or what was the current state of your brain? So that is what this is generally epoch. You divide your entire EEG waveforms in response to a particular event and chop it up into a different, different parts, club the area of your interest, club all the epochs. And once epochs are generated, you take averages.

Now, why do we need to repetitively give events like this, this, this, this, and this, there is a reason. Your brain reacts to different event in a random way. So at first time, when you give a particular event, it need not to be showing you exactly the response you would like to see. So that is why you need to perform certain number of epochs. There are literatures on how many epoch should be performed.

Generally, for normal auditory epochs, we perform 100 epochs or something. You can even go for more 120 or something. For vision-based experiments also, you can go for this many amount, and then you do time pointwise or timewise, pointwise averaging, and then it will give you the final trace. So all this red colour blocks will come together, and finally you will get something like this. You can see that there is some deep and something, this is just an example.

So from all this green colour thing is nothing but your EEG. Green colour thing is EEG. Blue colour is your event, or any kind of, in other neuroscience term, you even call them event or stimuli. If it is image, visual stimuli. If it is sound, then it is auditory stimuli. So then finally, after averaging out, consider all pre-processing also done, and you got an value for minus 100 millisecond to 500 millisecond, averaged value.

This thing is nothing but your ERP, event related potential. So you should know that how this transformation from EEG to ERP happen. So again, same thing is being shown here. Let us say instead of some neurofeedback or something here, we are putting, also we are presenting some stimuli generation unit I just say sim-SG, then signal will be acquired and transmitted and then extract the information. Based on the information you can also give some kind of neurofeedback that this particular band is active, this band is this, like this, this sound is perceived or not perceived. And then you perform some form of decision-making task here. So this is like overall idea about the ERP.

The key thing is you should know what is the difference between EEG and ERP. ERP is just a time logged average value, a part of EEG only, recorded for multiple amount of time.

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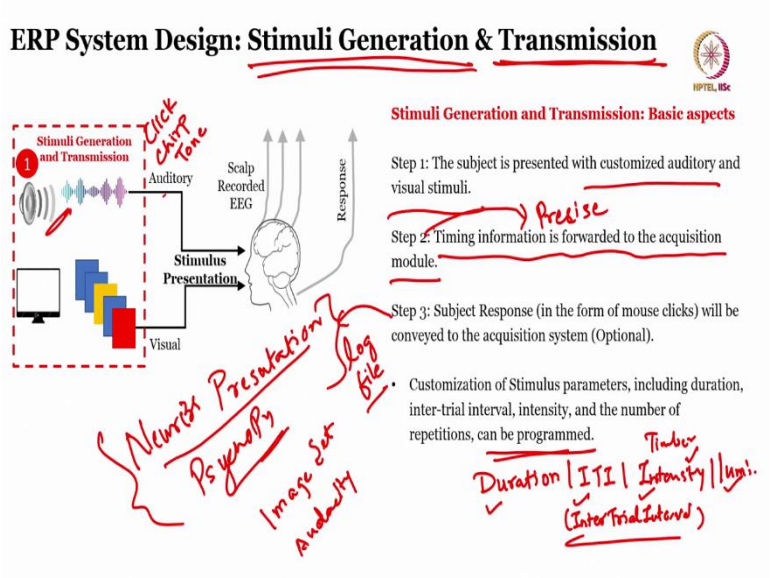

So let us quickly move ahead and see the basic building blocks of any ERP system. First, as I mentioned, it starts with stimuli generation and it can be customized, it needs to be customized. You can see here using speaker and all. If you want to generate a sound. And then its script needs to be written, there are several softwares. One is known as Presentation. You need to take a license for that. It is from Neurobiobehavioral System, NeuroBS.

Then you can even go for PsychoPy, python-based software to generate different kind of stimuli. Both the cases you have to take care how you are giving timing information to your acquisition board. Very important. I always feel that stimuli generation is equally important step as stimuli transmission. It needs to be very precise. Otherwise, you will not get a correct timing information. You will end up getting a wrong signal.

So both the stimuli will be instantiated in NeuroBS system, but it needs to be generated. If you are working with this kind of images, you should have a proper image set for visual experiment. And when you talk about auditory sound, there is something called Audacity. It is another software which you can use to generate different sound, different tones, different click, different chirps. All these are known auditory stimuli. What are this? Click, chirp, tone, et cetera. You can explore by your own.

Again, when I talk about this auditory sound, it can be characterized, any stimuli should be characterized by duration, ITI it is called inter-trial interval. Intensity. When I say intensity, I am talking about auditory sound. It can be luminance for visual sound, timber. All this thing

can characterize your stimuli. How your stimuli is shaped up or why you have used? And each thing should be optimized, identified for one particular event related potential.

So important points about stimuli generation and transmission units, that subject is presented or whenever you perform experiment, there should be a customized auditory and visual stimuli, with all these parameters set and identified. I also mentioned that timing information is forwarded to the acquisition module. Very important. I would say not only timing information it should be very precise timing information should be conveyed.

Further, in some of the experiment, it is required that you are recording a sound or once your sound reaches to a subject, you ask them to click it. Once a particular image comes, you ask them to click it, this kind of thing. So user response or subject response is also equally important, and that is also logged in this kind of software when you are generating stimuli, they also takes care of obtaining user response and save it for one particular file.

Everything, all this information comes under log file, whether it is event, whether it is response, et cetera. Which helps in further processing this particular thing. All this thing I mentioned, this can be programmed in this softwares.

So briefly speaking about this thing, important aspects is stimuli generation. It can be done using several softwares. You can instantiate whichever amount of image and sound you want to, also you can program it and you can configure it, customize it as per your application.

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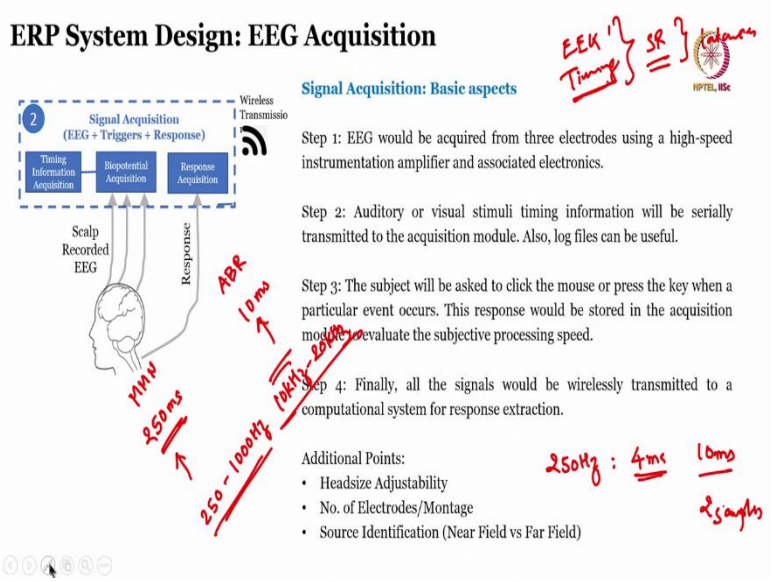

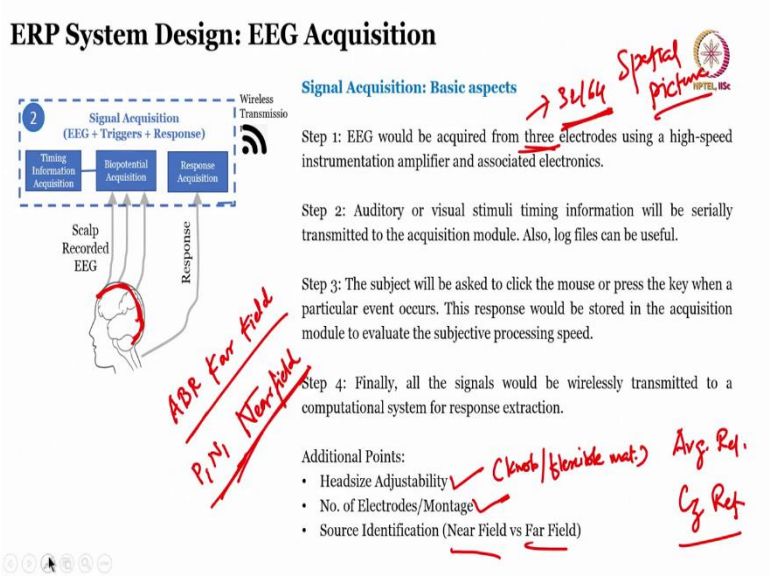

Let us move ahead with the next submodule. This is signal acquisition. So what are the things would be acquired? One is I already mentioned EEG, or you can say neuropotential. Other thing is timing information. These two things are crucial. When you acquire anything, it is very important you should well aware about your sampling rate, what is the latency you are targeting. Let us say if I am talking about something called MMN.

So MMN is nothing but that occurs around 250 millisecond or something, 250 millisecond. So I need handful of many samples before 250 millisecond. So anything within 200, 250 to 1000 hertz should be good enough to record this MMN.

Whereas if I talk about ABR. ABR is auditory brainstem response comes within 10 millisecond of sound presentation. So same thing cannot be used because if you use 250 hertz board, then it is like 4 millisecond. This 4 millisecond, and you want to record 10 millisecond signature, you will only get two samples. So, which is not a correct way. So based on your application, you should be able to design that which kind of acquisition system with which range of sampling rate you should use it.

In this case, we should at least use a sampling rate of 10 kilohertz to 20 kilohertz. This, you should identify by your own, that which kind of sampling rate for which kind of application should be used. So that was my first point that it would be acquired from, here it is written three, need not to be three it can be more, it can be less. People are recording from 32, 64, general EEG also and even beyond that, if you have a micro electrodes and all to get a better spatial picture.

If you are recording something called far-field, you do not need this many electrode. One electrode is also fine. Based on your application, you can identify that and then this would be transmitted. I have already discussed about stimuli generation and all this thing. A response also can be adjusted.

There is some other important point is headsize adjustability. Not my, and your headsize is same. So there should be some provision either you add some knob or you use some flexible material. Ideally for EEG headband, it should be a proper mixture of flexible and fix resin or fix devices, when you 3D print it. 3D printing is I believe already covered in one of your module or will be covered.

So there you will see this kind of variables and it is like niche area, which on, which many people are working on and which kind of wearable system you should have. So you have to consider all this thing. Like another very important point, how many electrodes you want? Very important point. Less is better considering the comfort of human, but if you want to extract more information, you need more electrode.

If you want to have a better picture, as I just mentioned, that more number of electrode 32 to 64 to get a better spatial picture, you should go ahead with more electrode. It will result in more computational power but gives you the more information. Whereas if you are talking about some event related potentials or something where sources are already identified. Vision related experiment, you should mostly record it from parietal or occipital lobe.

So if this kind of information is already there, you should directly go ahead with those kind of source and generators with limited number of electrodes, which makes lives easier for subject also, computational power also. And there will be less number of variable associated with that. So you can take a wise decision based on your application that which kind of electrodes should be used.

Another thing is montage, which reference and ground you are considering. There are different montages called average reference montage, where you will take average of all the electrodes, Cz reference montage. You can think about all this thing. You can explore more about that, that what is montage and all. Basically, it is the way to acquire the data, which electrode you are considering as a reference compared to other electrodes.

Further, you should know that near field and far field. So far field is something which is constant across your brain. You put electrode, any of the surface, you will get equal response of that particular signature. ABR is one of the far field response, auditory brainstem response is far field. So what is the meaning of that? You can put anywhere on your head, you will get constant ABR, whereas if I talk about P1, N1, so this is known cortical auditory work potential.

For this, I will put it in a several places, I will get different response. That is why it is called near field. So the application or the signature you are trying to measure that you should identify whether it is near field or far field, accordingly, you can design your system. So this is a very basic aspects about signal acquisition.

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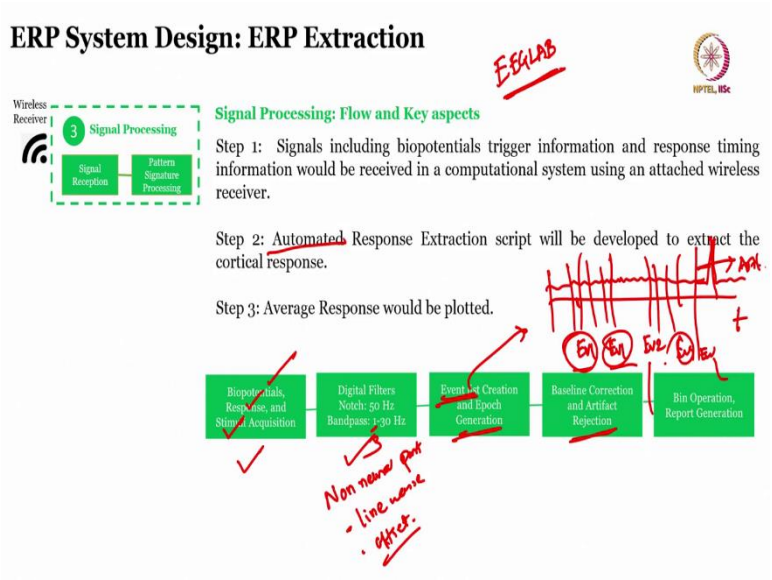

And next we will see signal processing. So processing involves several steps. It must be automated and there are softwares to do that. There is a plugin to MATLAB in EEGLAB. I will put in some other course my previous videos link so you can see the basics of EEGLAB, how to download it, how to use it, how to analyse data using EEGLAB and all.

Maybe at the end of the video I will put the QR code images for that, so you can quickly look at that and have an idea how it is used to process the EEG and make a neural sense out of that. Once you get the data you do some filtering to remove the non-neural part.

What is the non-neural part? It can be line noise, some offset. That is why you will not take 0 hertz or something. You could start from 1 or even, you can start with 3 to remove all the low noise drips. Once you get all the information about your biopotential, your stimuli and timing

information and response, you can make a event list. Event list is nothing, but when your experiment happened, remember the example, this kind of thing.

At what time, at what period of this is time, at what period of time which kind of sound was presented? What event? Let us say this is event one, this is event two. So when event one was happened, when event two was happened, all this thing will comes under event list. Then once event list is done, then you want to know, okay, I need minus 50 to plus 500, minus 50 plus 500, minus 50 plus 500. That is what you call as epoch generation.

Once this is done, you can eject the artifact. So this value is, let us say this all is within the range, but there is some this I know additional, this kind of serious transition instead of the one what you, I will just show it to you again. Let us say this is your EEG. This is your normal EEG, but after this, suddenly something happened, and you got this kind of block. So when I consider this particular event, and I take from this to this, I will not consider this because this is nothing but some artifact, which is non-neural.

So that all things will be taken care in artifact rejection, and then you club the same event in one bin. And then you do the averaging and finally the plotting and all. So this is in a very nutshell, in a quick overview of what the signal processing system does.

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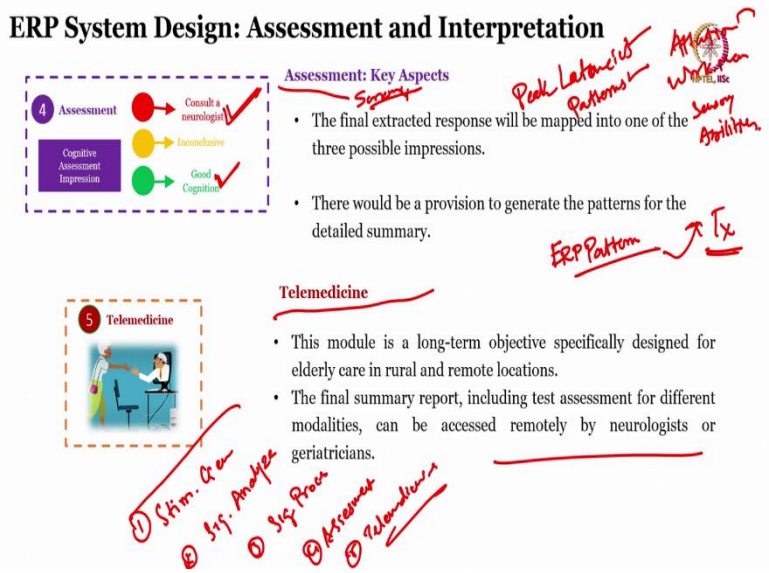

Further to quick module we will see another thing is assessment. So whatever your final response comes, that can be assessed by latency or in a more precise term, peak latencies. Then you can also identify the patterns. And then you can come to a conclusion whether that person

has a good cognition. Here, I have given an example of cognition. So whether a person is attention, working memory.

Even other sensory abilities, this all comes under cognition. So if it passes the test, the final peak latencies are present, the pattern is there, then you can say that yes, it passes. If not, then you have to consult a neurologist. So it is basically, more or less screening approach, three stage screening, like a traffic signal, red, green, yellow, and then you can do this experiment.

Further there are several approaches. This all ultimately as I mentioned, will be converted into your final ERP pattern. So this pattern will be saved in terms of image and all, you can further transmit it wherever you want. This is especially for telemedicine, for remote areas and all, and that finally, neurologist who is sitting remotely can interpret your final pattern and conclude that, okay, you might have to need assistance for this particular thing, that particular, et cetera.

So these are, again we have seen how many things. First is stimuli generation. That was the first module. Second was signal acquisition. Again, this all are very, very generic. You can think about any of the application and map it into this particular fundamental blocks. Then signal processing. Fourth one is, you can see here top assessment. And finally, telemedicine. Now, this is like overall fundamental building block of any ERP based or EEG/ ERP based experiment.

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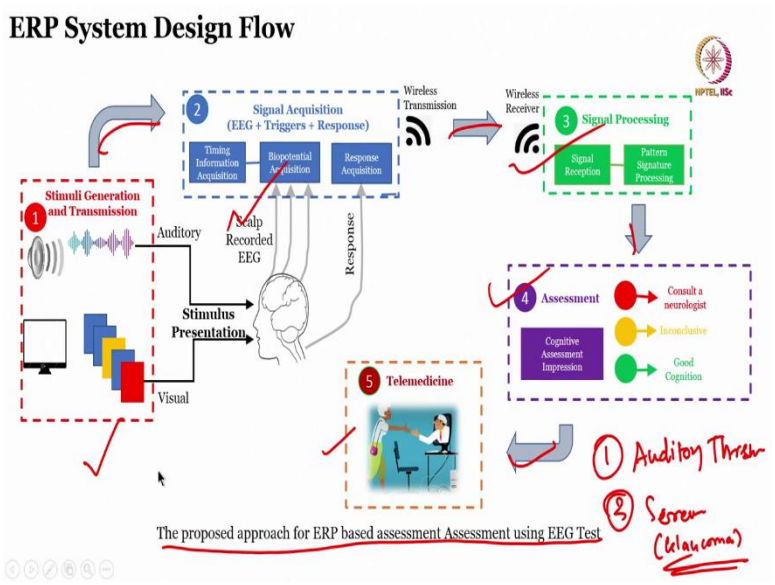

Now let us see how quickly the entire thing looks like. So this is like overall, whatever we have discussed so far in this ERP based assessment using EEG. I would request you to go through

the entire cycle. You can see the direction from 1, 1 to 2, 2 to 3, 3 to 4, and 4 to 5. You can think about one application. Let us say, think about auditory threshold because I more or less work with auditory stuff.

I can come up with this kind, but you can go for your any of your example, any of your ERP based example. Let us say screening for one particular disease or glaucoma. So that one makes it a visual screening, visually or potential or visual ERP screening. Think about that. Map it to each of the module and try to sketch at least some rough outline about your final ERP experiment.

So this is a gist of what I wanted you people to know about EEG ERP experimentation. How to design it. Very important. What are the things we need to take care? And this in all next time when we meet we will see the known applications quickly and what are the protocols you need to think about. So till then all of you, please take care. Bye.