Foundations of Cognitive Robotics
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Lecture - 10

Good morning, students. Welcome to the course on Fundamentals of Cognitive Robotics and today, we are going to talk about a very important part of cognitive robotics experiment. We are going to talk about EEG experiments, because in order to you know what is there in a human brain from a robotics perspective, in order to develop a brain computer interfacing it is absolutely important that we understand how to know what is happening in the human brain.

That is what we will be discussing today that how to carry out EEG analysis and through that how to know about the state of a human brain. Let us look into that.

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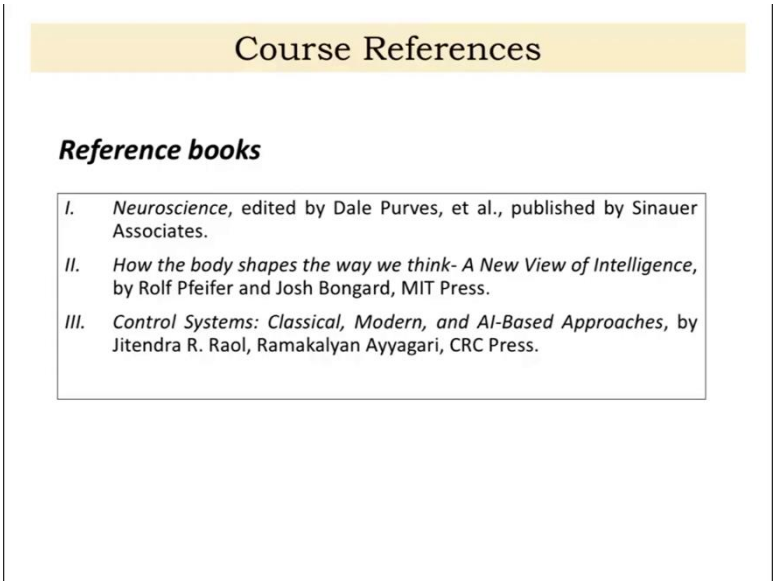

I have talked about some of the reference books which will be useful now particularly the first and the third book that is the Neuroscience book which is edited by Dale Purves and the Control Systems: Classical, Modern and AI-Based Approaches these are the things which will be important at this stage.

So, you can catch hold of these books and you can also try to get reference materials related to the lecture.

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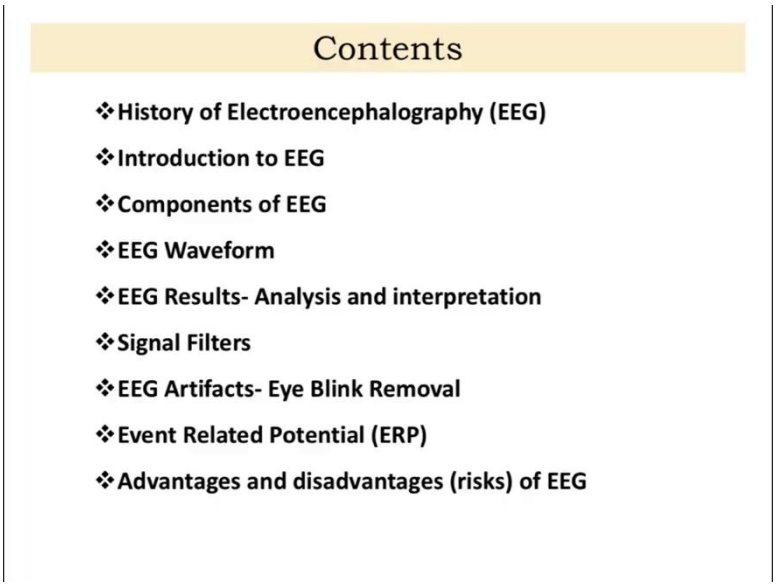

Now, in today's lecture we will talk about the history of electroencephalography or EEG a little bit of it. We will also give a kind of a introduction to the EEG analysis, various components or elements of the EEG analysis, then we will talk about the EEG waveform, EEG results – analysis and interpretation, signal filters that are used in EEGs, how to use you know some of these filters specially for artifacts like eye blink removal.

And, one of the most important thing against external stimulus how to use the event related potential information and finally, I would also talk about the advantages and disadvantages of the risks of the EEG.

There are various ways in which we can find out the state of a brain. So, EEG is one of the way in which we insert electrodes over the scalp of a brain. So, it does not penetrate the body, it remains over the scalp of the brain that is one way and then there are other ways.

For example, there are ways which are related to MRI and specifically called FMRI which actually finds out that as the blood flows inside the brain and as this blood is getting oxygenated, you can say that somewhat that those are the regions where more oxygen supply is happening you can say indirectly that nerves are more active in those areas.

So, if there are more presence of blood flow then naturally because blood contains a good amount of iron particle in the form of haemoglobin. So, the magnetic resonance you know

would be able to catch it and then from that we will be able to get a kind of a pattern that is happening inside.

However, these techniques of MRIs and FMRIs they have a very good spatial resolution because many parts of the brain what is happening that they can capture, but they do not have a good temporal resolution; that means, over time they are actually very slow, on the other hand EEG is very fast. It can very quickly say what is happening in the brain.

So, in fact, today a mixing of the two technologies it seems to be a much better way of actually analyzing what is happening in the brain. So, before looking into the EEG let us first very quickly look into all the other available technologies.

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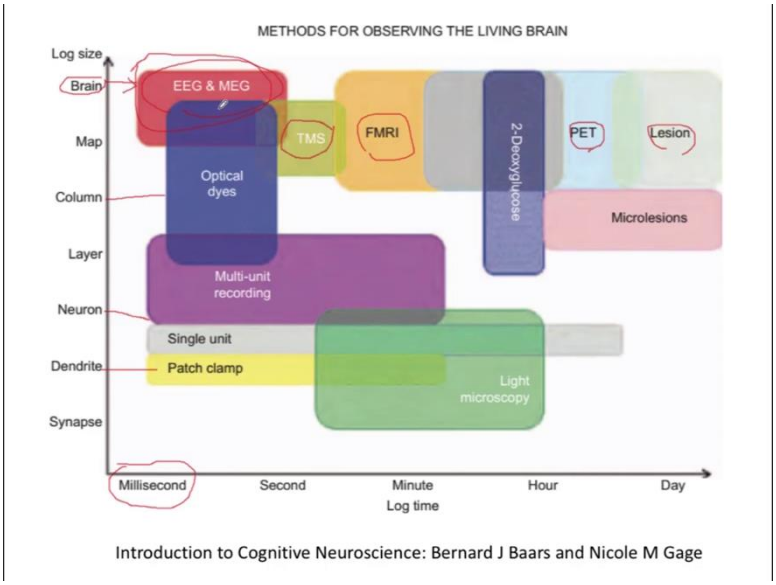

Now, there are various methods as I told you for observing the living brain and in terms of time those which are slow will be in the right hand side of it and in terms of time those which are fast they will be in the left hand side. Say for example, EEG and MEG is there in the left hand side because they are very fast phenomena whereas, FMRI is relatively slow and the PET technology or other studies of lesion etcetera these are very slow.

Now, in terms of the size that it covers because the brain is a large area. So, there are actually tests like patch clamp tests which are in the dendrite level and then a single neuronal unit also can be tested once again by placing the electrodes directly over the neuron and at a higher level there are these optical dyes and of course, when the entire

brain is concerned then you can actually make a network of EEGs or MEGs and through that you can actually check it.

There are other technologies which are just coming up which is like TMS which is somewhere in between the EEG and FMRI technology. So, this actually gives us a global picture that where these EEGs are and we can say that EEGs are a process of analysis which is very fast millisecond level, but it works in a global scale on the full brain. So, that is something that we have to keep in our mind.

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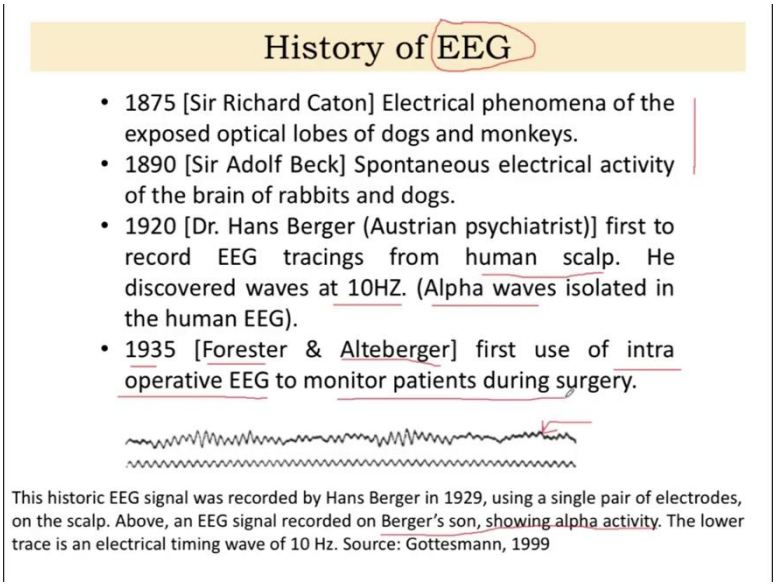

Now, I will talk about a little bit about the history of EEGs. In 1875, Sir Richard Caton of Liverpool is credited that is the first person to actually apply the EEG technique the electrical phenomena of the exposed optical lobes of dogs and monkeys. So, essentially he had literally opened up the dogs or monkeys brains and then on the optical lobes he has actually inserted the electrode and then he has found out that yes, there is the electrical pulse that are associated with it.

Later on, Sir Adolf Beck he has actually find out that in rabbits and dogs there is this spontaneous electrical activity of the brain that is happening. And, even later in 1920 Dr. Hans Berger in fact, we have the one of the waves of brainwaves alpha wave is named after Berger's wave and he is credited to be the first person to actually talked about something like an EEG because so far in the first two cases these two cases it was actually open brain surgery,

during that time it was tested, but during doctor Hans Berger experiments he was first able to record EEG tracings from the human scalp itself and he discovered waves at a low frequency like 10 Hertz in fact, alpha waves is what he has looked at. So, this is something that actually shows the original wave that he has in fact, looked into and you can see this is an alpha wave which is a very slow paced wave.

In fact, he carried out this experiment on his own son showing the alpha activity. So, that was the first time you know the EEG is kind of it was proved that EEG can actually pick up some interesting signals from the brain and later on in 1935 forester and Alteberger they have used these for intra operative EEG which means during surgery they have used this similar way of taking the signal so that they can monitor the patient state during surgery.

So, that is a brief history about the EEG.

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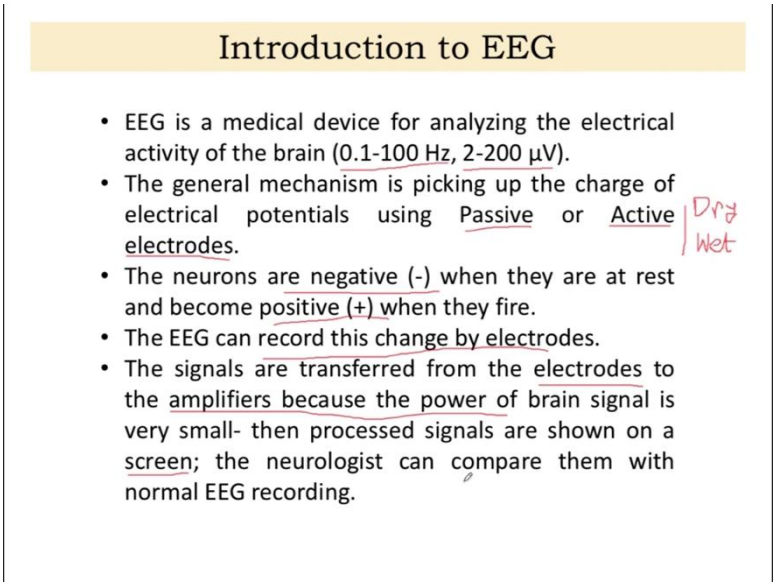

Now, let us introduce that what is this EEG test all about. Well, EEG test is all about a medical device development for analyzing the electrical activity of the brain. The frequency range is between 0.1 to 100 Hertz and the amplitude of the voltage is quite small it is about 2 to 200 micron volt.

The general mechanism by which it works is that it picks up the summative charges of the electric potentials using either passive or active electrodes. Now, the difference between

the passive and the active electrode is that passive electro electrodes are generally not fitted with any amplifier. But, because the signals are very low sometimes it actually microvolt range it make sense to have an amplifier on the electrode itself. So, then it becomes actually active electrodes.

Now, both passive and active electrodes can be actually divided to further sub classes which are known as dry electrode. This will be dry electrode and wet electrode. Well, the difference is in terms of that in case of a wet electrode we actually apply some kind of a silver chloride gel on the brain and then apply these transducers.

But, for dry we do not do it and generally dry electrodes are used for kids who are very you know dynamic. So, wet actually creates disturbance for them, so that you do not get the desired brain picture. So, that is why dry is generally preferred for such cases, but it is not so accurate as the wet electrode.

Now, you may remember that I said earlier that the neurons are negative when they are at rest, is something like -50 to -60 millivolt potential, but the moment a neuron is firing it becomes positive and if there are group of neurons firing then there is a lot of positive charges developing.

And, the EEG record this summation of charges by the electrodes and these signals are transferred from the electrodes to the amplifiers because the signals as I told you is very very small and then their process signals are then shown on the screen, sometimes it is recorded also. So, this is what is the basic way of carrying out the EEG.

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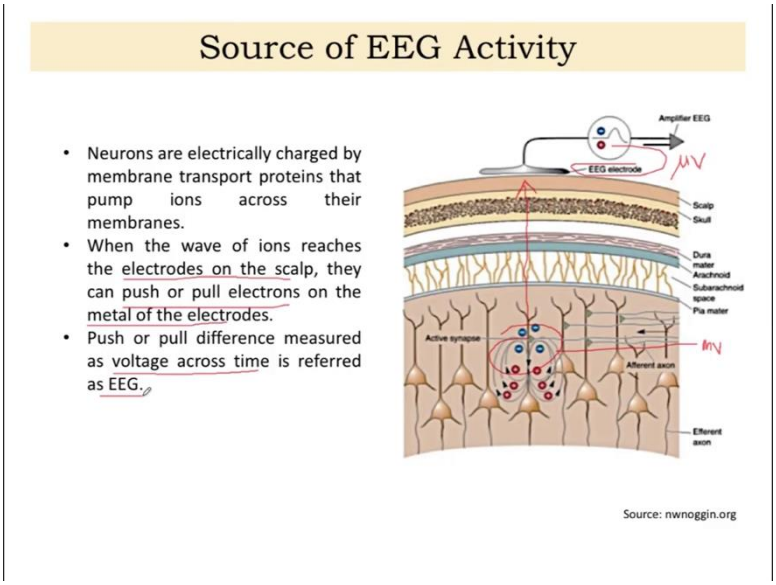

Now, the source of the EEG if you look at it very carefully you see that there are so many neurons here and thus is deep inside the brain and as they are getting charged as you can see here that the active synapses are here then these charge are actually coming and of course, on their way they gets reduced a lot, but they are coming towards the scalp and electrodes are actually going to pick them up.

So, you can see that in between there are so many areas that they have to cover actually. And, naturally it becomes more and more feeble because here at this level it may be in the milli volt range that we have earlier seen about the neuronal impulse conduction, but by the time it reaches here it will be in the micro volt range. So, so much of charge dissipation takes place.

So, whenever the wave of ions reaches the electrodes on the scalp then they can push or pull electrons on the metal of the electrodes and that is where we get the signal. So, this push or pull difference is actually measured at voltage across time and that is referred as the EEG signal. So, that is what is the source of the EEG signal.

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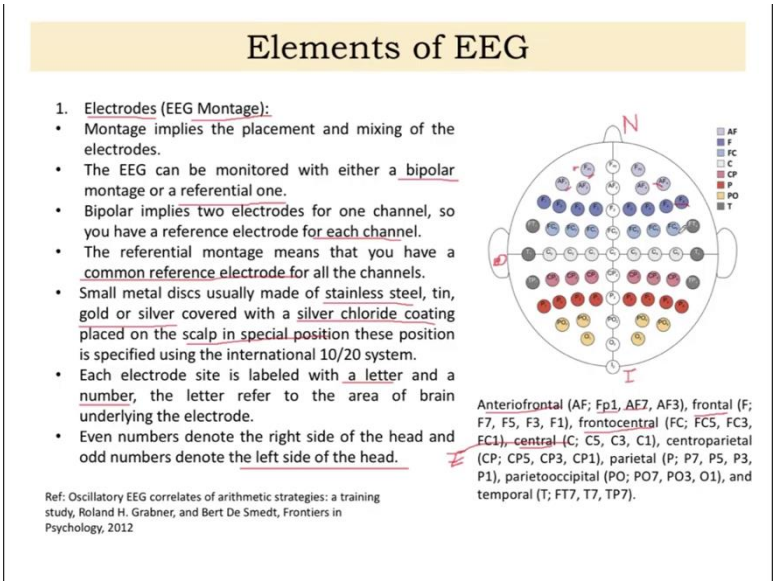

Now, what are the basic elements of EEG? Well, one of the most important thing about doing EEG is to know that where to place these you know electrodes ok. So, the electrodes how to place and how to make actually pairs of these then that actually will develop or will be defined in terms of the montages. So, this actually refers to the placement and mixing of this electrodes that how we are pairing it up.

Now, the EEG can be monitored with either a bipolar montage or a referential one. So, if it is a referential one, generally we take the reference near the earlobes or if it is a bipolar one then each one of them will be having its own references. Now, bipolar implies two electrodes for one channel. So, you have a reference for that channel available for each channel itself, otherwise you can have a common reference electrode as I told you which is usually close to the other.

And, small metal discs usually they are made of stainless steel or tin or gold or silver, the more expensive you would go for and they are covered with a silver chloride coating, they are placed on the scalp in special position and these positions I will show you that this positions are referred as 10 – 20 system.

Now, each of these electrode positions are levelled with a letter and a number. For example, you can see here that Fp1, AF7 ok. So, F and AF that is anteriofrontal and then only frontals ok, then frontocentral that is FCs, then only central that is C; some people call this C as Z also.

So, in some things because in German central is zentral, so, some people refer them as Z also. So, C, C5, C3, C1 and centroparietal, parietal, parietooccipital and temporal – all of them you can see the abbreviations here.

Now, the other abbreviation is in terms of this numbers you might have noted. Well, the odd numbers would mean that it is in the left side of the brain. So, you can see that this side this is where it is in the left side of the brain, and the even numbers would say that these are in the right side of the brain. So, all these numbers will be right side of the brain.

Now, the other important point that I will tell you is that keep these points in mind that this is where is the nose and this is where is the occipital region, there is a tip at the occipital region and we call it as inion. So, these are the two with respect to which we actually spread it. Spreading of neuron is, spreading of electrode on the brain is an art on its own.

So, there is a rule that is called 10 20 rule I am going to explain it to you now and this rule is made so that at different places of the world if this EEG test is happening, then there will be a commonality people will not get confused between the positions. So, these are the universal positions which is common all over the world.

So, whenever wherever a human scalp is getting tested, they do it with respect to these positions and then they report the data and others can easily understand because these are all universal locations. So, it is very important for us to understand these universal locations.

Let us look into them.

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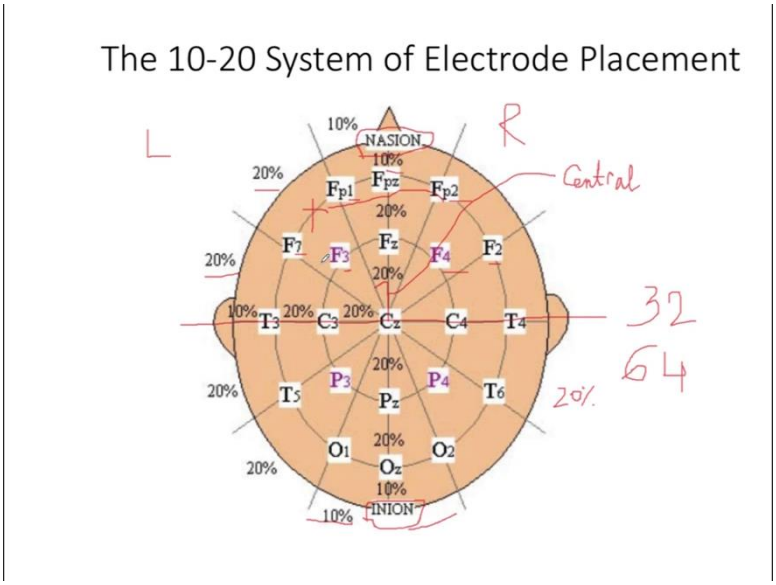

As I was telling you earlier that the first thing before placing the electrodes you have to mark is just above the nose is our nasion part and behind the brain there is a little lump if you check your occipital area behind the brain that is called inion part; so, nasion and inion. So, and the line that actually joins them this is the line that is what is the central line. So, this is the central line.

So, you have to keep the central line in mind and everything is either there are places which are left to the central line, this is left and this is the right part. And, you remember that left all numbers are odd 1, 3, 7 etcetera and right all numbers are even that is one way to know which one is left, which one is right.

Now, the other thing is that so, with respect to this central line if I go up to 10 percent from the and this line is also known to us because this goes to the earlobes. So, these two lines are actually known to us beforehand. So, that means, I can actually measure this you know and 10 percent of the distance that is where inside also 10 percent we actually place our first series of the electrodes ok. So, Fpz, Fp1, Fp2s, etcetera.

After that next placings are all at 20 percent, 20 percent. So, whatever is the total length 20 percent of it that is the distance where you place it everywhere else and again for the inion 10 percent by the two sides of the inion left and right and all other areas are actually all other areas here these are all 20 percent. So, this is the 10 percent, 20 percent rule that we follow and based on that we actually place the electrodes.

Now, how many electrodes can we place? Well, we can place as you can see here that very easily we can place in this manner you can see that there are central you know 5 electrodes and then here you can see that there are 5 and 3, 8. So, 8 and 8, 16 electrodes are there and center there are 5 electrodes and there are others which can go up to 32 electrodes EEG machine. There are even other EEG machines which can go up to 64 electrodes.

So, you know there are various ones, but these are the basics that you have to cover and these are to be placed when I say Fp1 the position is fixed that is it is 10 percent from this side and 10 percent from this side, that is where the Fp1 has to be ok. And, then in between you can add many mores that is not a problem and then you can accordingly you know put this left odd and right even numbering system and the locations also you can number. So, that is the way we use the 10 20 system of electrode placement.

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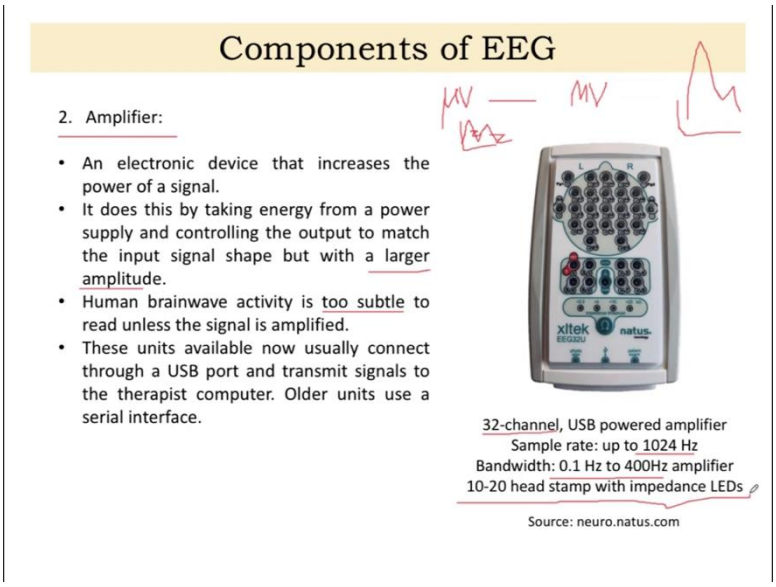

We will now look into different components of the EEG. Now, as I told you that first and the foremost important component of an EEG is actually the amplifier. Why the amplifier is required? Because you need to actually amplify the signal which is initially at micro voltage level to something like a milli volt level, so that we can easily analyze it.

So, you need an amplifier, but when you will be amplifying you will be amplifying the noise also. So, that is where the role of amplifier is so important that it not only should amplify the signal.

Now, let us say that this is the original signal and after amplification. Let us say this amplifies, but also it should removes let us say if there are noises here it should remove those noises ok. So, it should be a noise free. So, that if there are noises in between those noises should not appear here. So, it has to amplify also keeping in mind the filter of it.

Now, it does this by taking energy from a power supply that is why you need a power supply controlling the output to match the input signal shape, but with a larger amplitude. And, human brainwave activity is too subtle to read unless the signal is amplified this units are available now they can usually connect through a USB port and transmit signals to any therapist computer and older units have a serial interface, but now there are much better interfaces available.

So, in a typical amplifier there can be 32 channels the sampling rate can be 1024 Hertz bandwidth can be from 0.1 Hertz to 400 Hertz. Of course, up to 400 Hertz you do not require as I told you that may be up to 200 Hertz is good enough and also head stamps with impedance of LEDs. So, that is what is the first important component of the EEG.

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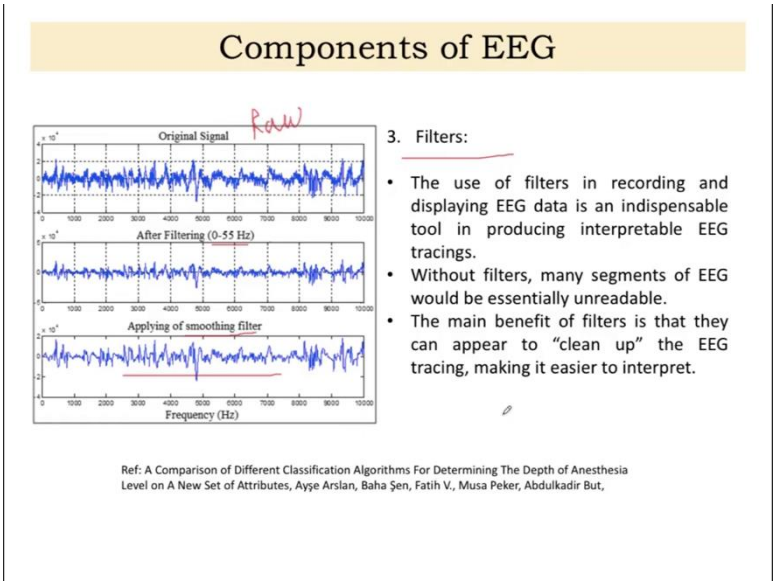

The next important component of the EEG is in terms of the filters. As you can see here that these filters they use these filters, so that the original signal noises you can actually attenuate depending on where you want to do it.

Like in 0 to 55 Hertz, after filtering you see this attenuated knowledge signal and then you can also apply smoothing filters. There you can get an even better one and so, that is how you can actually apply the filters. If you do not do it, then the data will be almost unreadable.

So, that is why you need to clean up the raw data. So, this is also the raw data the first part you need to clean it up by actually applying the filters.

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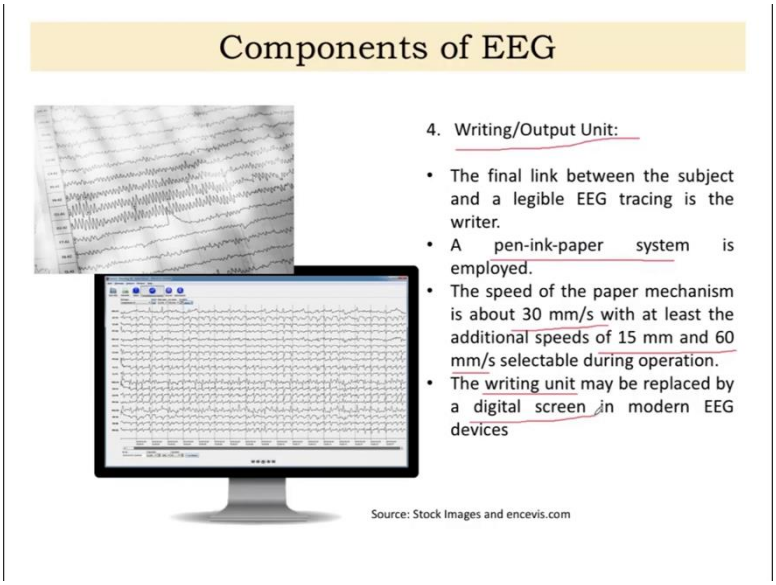

So, we will talk about the filters. Now, the next point of course, is after filtering you need to put that output. So, earlier days the output used to be using a writing unit and in a pen-ink-paper system, but today you know it can.

So, the at that time it was important that what was the speed of the paper mechanism like 30 millimetre per second with at least the additional speeds of 50 and 60 millimetre per second, so that you can record the data. If the speed is low then you will be missing some of the high frequency components. So, that is where the speed is important.

And, today of course, the entire data comes in a digital screen which you can actually record digitally and you can then analyze the data.

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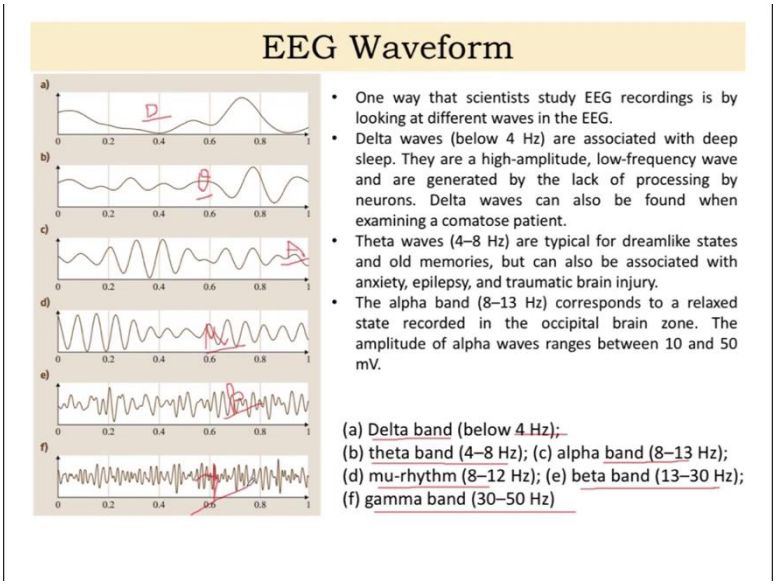

Now, whenever we talk about the EEG data, we have to know about the EEG waveforms. And, starting from the low frequency to the high frequency, the waveforms that would be coming up will be like delta band that is what is your delta band here and that is up to 4 Hertz. And, then you have alpha band that is 8 to 13 Hertz which is somewhere here; this is what is your alpha band. And, you can have a theta band in between which is 4 to 8 Hertz; so, this is what is your theta band.

And, then in the same 8 to 13 Hertz region or 8 to 12 Hertz you can have a mu-rhythm also. So, you can have a mu-rhythm. Now, you can see that both alpha and mu they share the same bandwidth almost 8 to 13 and 8 to 12, but the pattern of mu and the pattern of alpha these two are not the same, that is why it is little different. And, next then you have the beta band that is about 13 to 30 Hertz. So, this is your beta band and finally, you have the gamma band that is 30 to 50 Hertz. So, this is about your gamma band.

So, if you look at it very carefully the way it happens is that when you are in a very deep sleep, then this is the you know this is the delta wave range. When you are dreaming or day dreaming you are having episodic memories, then it is the theta; alpha is when you are simply taking rest, you close your eyes alpha waves will be automatically coming up within few you know minutes the brain signal will start to show the alpha.

Mu although is similar to alpha, but mu is different in terms of that it has it is related to certain activities processes etcetera; beta is when you are fully conscious and in fact,

thinking of some activity movement then it is beta and gamma is even higher when you are deeply concentrating on some task that is where the gamma will be coming into picture. So, these are the various gradations of the EEG waveform.

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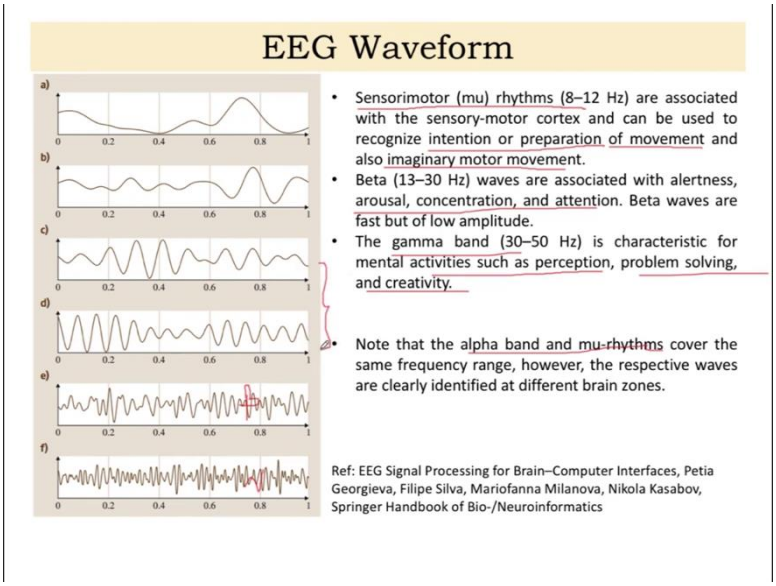

So, for example, here I have also mentioned what I have told you few minutes before that sensory motor mu-rhythms 8 to 12 Hertz even though they are similar, but they are they look different. As I told you the mu from the alpha and they are used to recognize intentions or preparations of movement and also some imaginary motor, this is where the mu-rhythm comes into picture.

Now, beta are associated with actually alertness, arousal, concentration and attentions etcetera. So, that is where the beta wave comes into the picture. And, then we have the gamma band that is the last one that is where is the gamma and this is the beta. So, gamma is for mental activities such as perception, problem solving, creativity etcetera and as I told you that even though alpha band and mu-rhythms cover the same frequency range.

However, the waves are different and you can clearly see that the waves are these two waves are different in nature. So, you can clearly see the differences.

Now, let us say you want to carry out yourself some EEG test you have a 16 channel or a 32 channel EEG setup available with you. So, the first there is a step by step process to

prepare the subject, we have to know it in order to get the good quality data. So, that is what I will be discussing.

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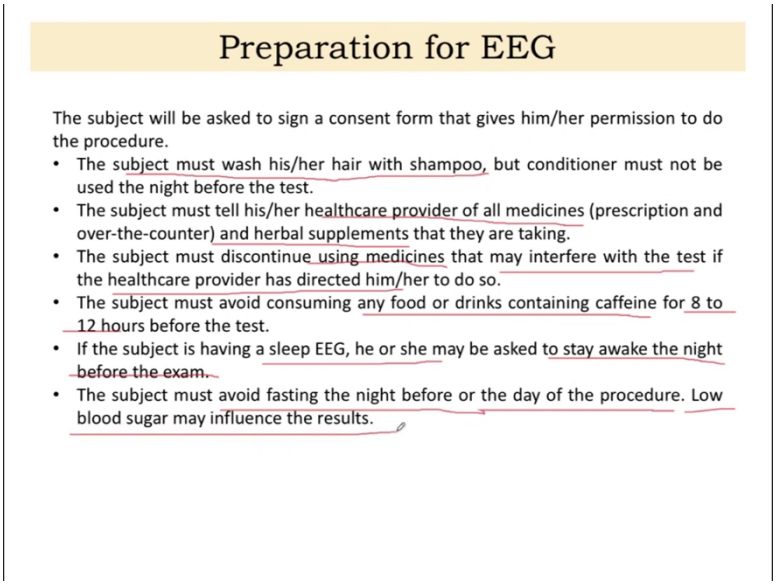

So, now, we will talk about the preparation for EEG and as you can see that first of all you have to take care that the subject must wash his or her hair with shampoo. Conditioner is not needed.

There should be as little oil as possible. So, that the results will not be tampered and the subject must tell his, her health care provider of all medicines prescriptions and supplements that they are taking. Important thing is that the subject should not have sugar and if there is sugar etcetera then there has to be some precautions that are to be taken.

The subject must discontinue using medicines particularly the subject is taking some neuro medicines, then they are to be discontinued because otherwise that may interfere with the test. So, if the health care provider has directed then this is to be done. And, then also another important thing, the subject must avoid consuming any food or drinks containing caffeine for 8 to 12 hours before the test because caffeine has some neurotransmitters that can affect the normal neuronal activity.

If the subject is having a sleep EEG sometimes we take the sleep EEGs, he or she may be asked to stay awake the night before, so that you can get a deep sleep and through that you can capture maybe the delta weights. And, of course, the subject must avoid fasting the

night before or the day of the procedure. Why because then there will be low blood sugar and that may also influence the results. So, you need to avoid the low blood sugar as well.

So, these are the basic preparations that you have to take.

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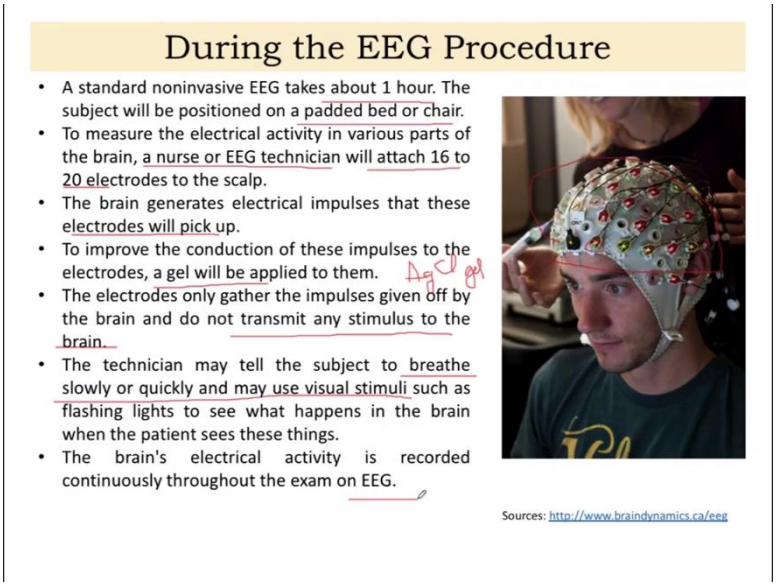

Next is what we will be doing during the EEG procedure. So, as you can see here that there is a cap and this cap is having it has actually taken care of the 10 percent, 20 percents more or less by these places where the electrodes are placed. So, a standard such EEG experiment will take about an hour you have to keep in mind and the subject will be positioned or a padded bed or chair you can do either way.

To measure the electrical activity in various parts of the brain there has to be a nurse or EEG technician will attach 16 or 20 electrodes, that is why is these electrodes are. So, 16 or 20 electrodes to the scalp.

The brain generates electrical impulses that these electrodes will pick up and to improve the conduction of these impulses to the electrodes a gel usually we use a gel of argentum chloride AgCl gel, that is what is used generally between this electrode and the scalps each electrode and the scalp.

And, the electrodes gather the impulses given up by the brain and it do not transmit any stimulus to the brain that is to be understood, that is to be told many times for the kids, that

is to be told to their parents that EEG is only a sensor. It is not going to put any signal to the brain. It only picks up the signals whatever is available outside the brain.

And, the technician may tell the subject to breathe slowly or quickly and may use some visual stimuli such as flashing light to see what happens in the brain when the patient sees these things and the brains electrical activity is all throughout recorded through the EEG testing. So, that is the way the test is carried out.

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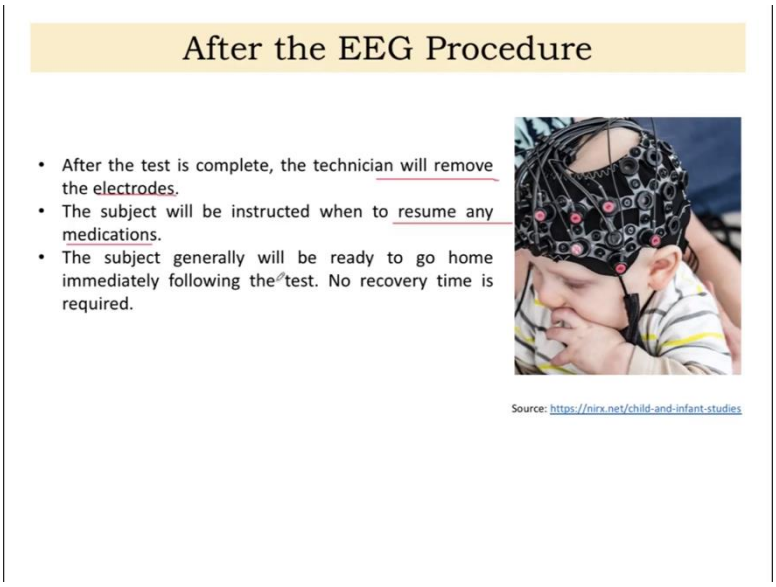

Now, after the EEG procedure after the test is complete, then of course, you are removing these electrodes. So, you need to remove, nothing is remaining on the body. The subject is generally instructed to resume any medication by the medical caregiver and the subject will be ready to go home immediately generally following the test and no recovery time is required for this. So, that is what is after the EEG procedure, very simple.

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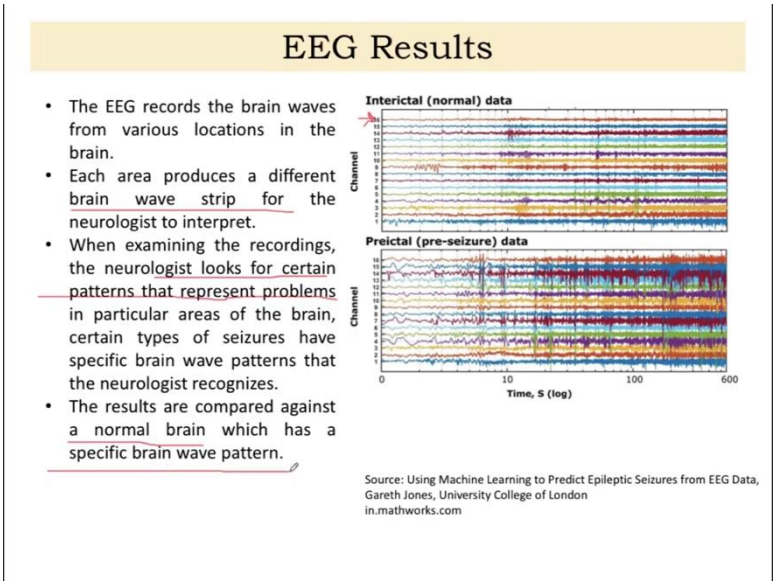

Now, here I am talking about some of the typical EEG results that you will get and you can see that when you are directly getting through from the channel how complicated looking they are.

And, in fact, in some cases if there is a seizure kind of a thing if then you may see this kind of you know activities that will say that there is something like a seizure happening. Otherwise it will be like a very complex noise you know train or a signal with a low signal to noise ratio.

Now, each area of the brain will produce a different brain wave strip as you can see here every channel has a different strip in it and when examining the recordings neurologist looks for certain patterns that represent the problems in particular areas of the brain because these are all channels and you know which channel corresponds to which area of the brain. And, the results are compared against a normal brain which has a specific brainwave pattern.

So, that is the way we actually work on the EEG results.

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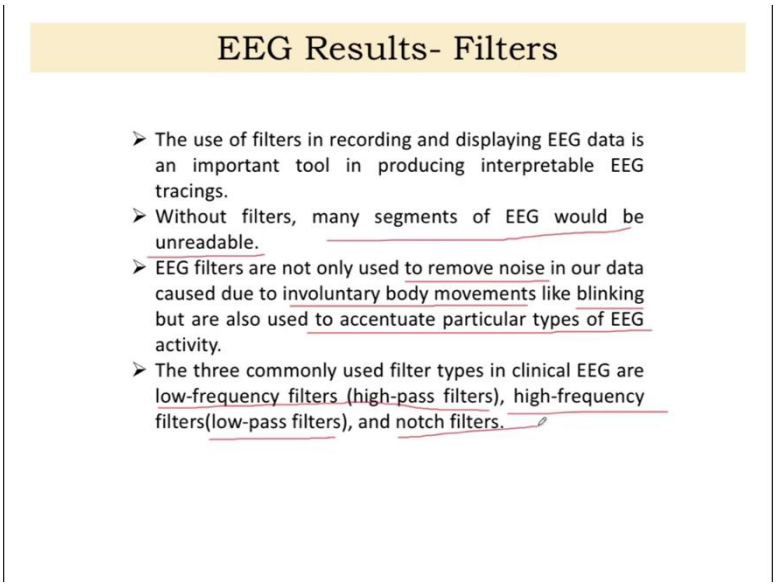

Now, at this stage it is absolutely important to use the filters in order to make the results of any sense. So, without filters many segments of EEG would be actually unreadable. Now, EEG filters are not only used to remove noise, but also involuntary body movements during taking EEG with blink many a times.

So, this blinkings are to be also filtered out. So, this is also needed to be done and the three common filters that we are using in such cases are low-frequency filter or also known as high-pass filter; high-frequency filter also known as low-pass filter and notch filters. So, these are the three that we will be using.

We will now talk about that what are these three different sensors, what is the constitutive relationships and how they are useful in each of the areas of EEG analysis let us look into that.

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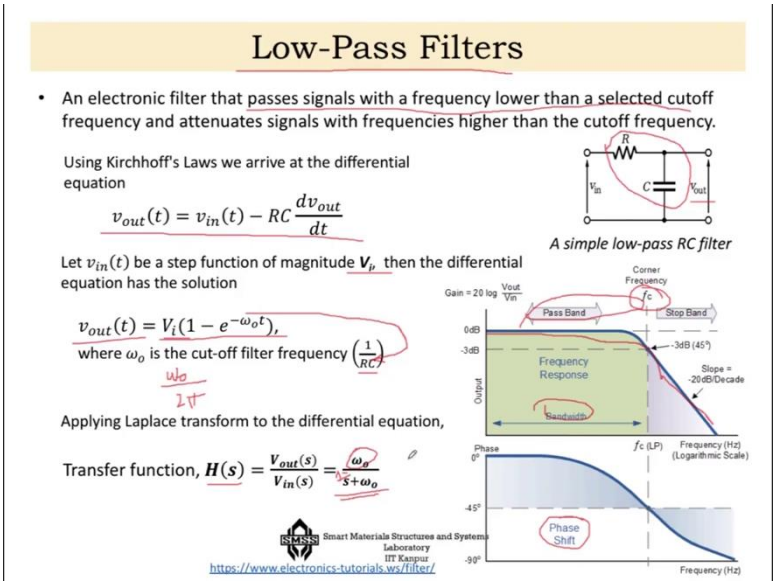

So, the first filter that we have talked about is a low-pass filter; that means, a filter which actually passes signals with a frequency that is lower than a selected cut-off. It allows those low things and the higher frequencies are actually filtered. Now, the way it is done is by using a RC circuit as you can see that there is an RC circuit that is used and the output voltage with respect to the input voltage here can be simply written by Kirchhoff's law as:

$$v_{out}(t) = v_{in}(t) - RC\frac{dv_{out}}{dt}$$

Where, $v_{in}(t)$ is a step function of magnitude V in that is the input voltage and output is coming out of the you know signal filter or condition. Now, this $v_{out}(t)$ can be written in terms of the input as something likes $1 - e^{-\omega_o t}$ you know that is common for a RC circuit and where this ω_o is actually these RC circuit.

$$v_{out}(t) = V_i(1 - e^{-\omega_o t}),$$

And, the cut-off frequency if we try to use it in terms of the corner frequency or cut off frequency, then this ω_o is which is in rad per second you have to divide it by 2 pi, then you will be getting that f_c.

Now, you can actually apply Laplace transformation to this signal and then what you will get as a transfer function is an algebraic relationship between $\boldsymbol{V_{out}}$ and $\boldsymbol{V_{in}}$ and that will be a first order filter like $\frac{\omega_o}{s+\omega_o}$. Now, because this polynomial is a first order s^1, so, that is

why this is also called as a first order filter. And, the response of the first order filter is usually in terms of this kind of a direct cut off as you can see.

$$H(s) = \frac{V_{out}(s)}{V_{in}(s)} = \frac{\omega_o}{s + \omega_o}$$

So, it is these are the pass bands by varying ω or the varying RC you can actually define the bandwidth up to which signal you will be passing. And, the same thing is true for the phase also, that up to which point the phases are to be retained. So, that is the fast low pass filter.

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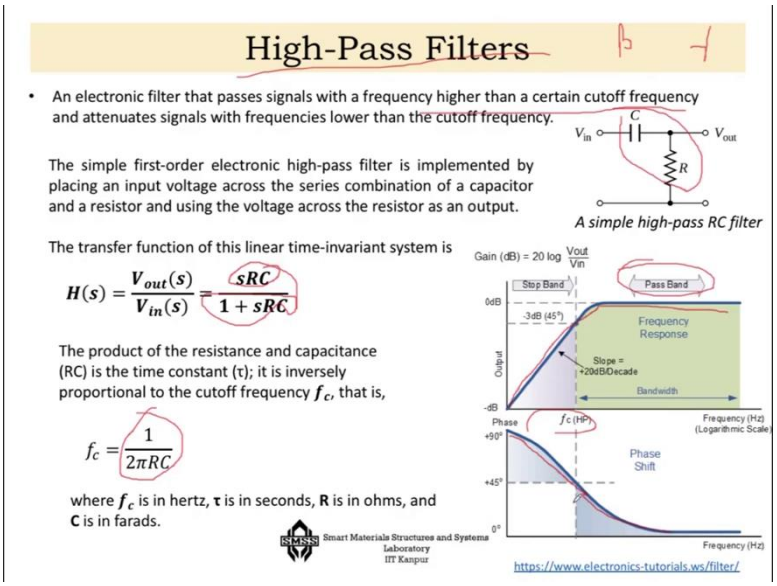

We will then talk about what we call a high pass filter and that means, it will be you know for the low frequency part will be actually filtered. So, it will be allowing the frequencies higher than a certain cut off frequency. Now, why this is required? As I told you that suppose I want to see a low wave something like a delta wave or an alpha wave then what I will do? I will go for a low pass filter.

But, suppose I want to see something like a beta wave or something like a gamma wave, then what I can do is that I can cut-off this alpha wave or delta waves and that is where the high pass filter will come into picture. And, as you can see here that this is where the C and R are in actually series unlike the last case and here the transfer function will then

become there will be a 0 in the transfer function in the numerator and denominator is the same.

$$\boldsymbol{H(s) = \frac{V_{out}(s)}{V_{in}(s)} = \frac{sRC}{1 + sRC}}$$

So, as a result of this the way in which it is filtering is just the other way around; that means, up till this point the gain is very low. So, it will not allow the signal to come and beyond this point then the signals are actually coming that is where is the pass band of the signal. And as I told you that this cut off frequency f c is actually $\frac{1}{2\pi RC}$ that is 1 over RC is $\boldsymbol{\omega_o}$. So, it is $\frac{\omega_o}{2\pi}$.

$$f_c = \frac{1}{2\pi RC}$$

So, that is what is an high pass filter. The phase is just the reverse in this case as you can see that initially there is a phase and as the cut off frequency is crossing, then the phase is actually getting filtered. So, that is the way the high pass filter is going to work.

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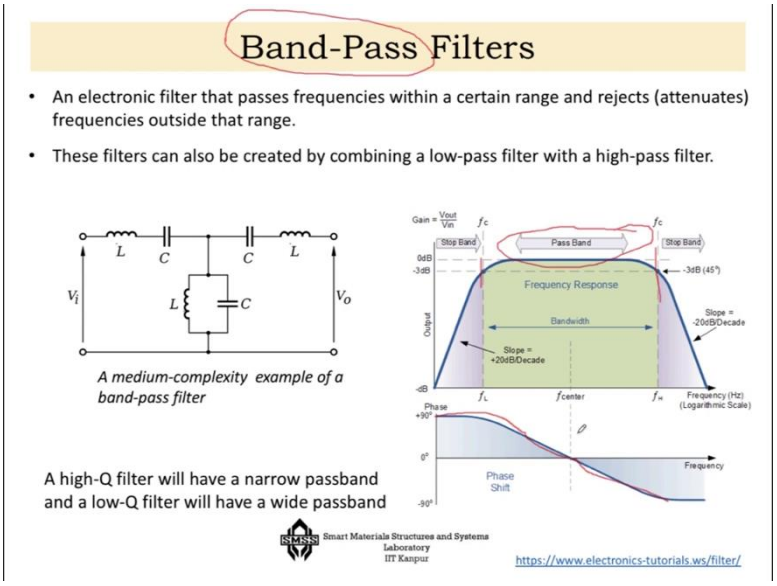

Now, you can have a combination of a high-pass and a low-pass. In that case what we will need is something which is called a band-pass filter. So, that means, some part of the signal initially is cut and some part of the signal beyond a point is stopped and the pass band is

somewhere in between. So, that can be also a frequency response and this is known as a band-pass filter.

So, essentially it will be as you can see this it will be a combination of some sort of a low-pass and a high-pass filter. So, that is what is the band-pass filter. As you can see that the phase here is also during the pass band it is actually changing the nature from positive to negative, +90 to -90 the phase changes its nature. So, that is what is a band-pass filter.

Well, low-pass filter, high-pass filter or band-pass filter they are good when you are actually chopping out some part of the EEG response and you are only looking at a particular band of the EEG response.

But, as I told you that let us say at this moment itself you can see that my eyes are blinking and if there is an electrode it is going to get that signal immediately and there will be a sharp peak there and many times that actually camouflages the actual signal. So, we need to filter that, in such cases we will be using actually something called a notch filter. So, let us look into a notch filter.

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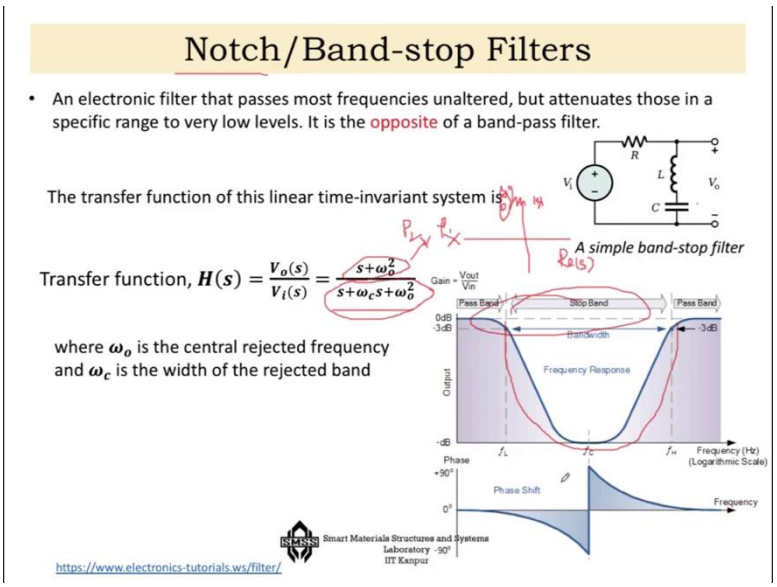

So, here we are talking about a notch filter. Now, what does this notch to as you can see the name itself is telling that it is actually notching under a certain band, it is not allowing any wave to pass and this notch filters are actually second order. So, far we had first order

filters, but here these are second order filters and you can see that they are having two 0s and also they are going to have two poles.

So, usually in you know if we draw the real versus the imaginary of x for such filters. So, let us say real s versus the imaginary of s then, it is going to have there are 0s there which will be in the high frequency range and followed by some poles which will be far away from the real axis.

$$H(s) = \frac{V_o(s)}{V_i(s)} = \frac{s + \omega_o^2}{s + \omega_c s + \omega_o^2}$$

So, this is what these are the poles P 1, P 1 and P 2. So, these poles are nothing, but the roots of the denominator. So, this is this denominator is going to produce these poles. And, the numerator which is also a quadratic polynomial is going to produce these 0s.

So, this is where you know is typically a notch filter. So, this is what is the amplitude and this is what is the phase that you can see that the phase shifts from 0 to you know -90 to +90 and then it comes back to 0 that is what is the notch filters phase characteristics. So, these are the amplitude and the phase characteristics of a notch filter.

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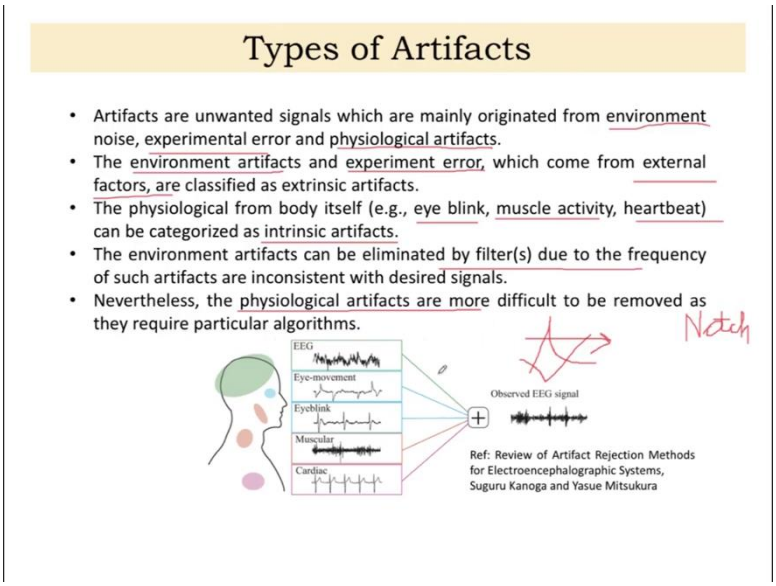

Now, the type of artifacts that I was just mentioning eye blink is just one of the artifacts. There are many different types of artifacts which can be originated due to environment noise, experimental error or some physiological artifact like the eye blink itself.

Now, environment artifacts and experimental errors and environment artifacts, they actually come from external factors they are extrinsic; whereas, the physiological form will be from eye blink, from muscle activity, from heartbeat, they are actually intrinsic artifacts.

So, the environment artifacts can be eliminated by filters, if you know what is the environmental characteristics, but physiological artifacts are generally more difficult to be removed. Of course, you can use as I told you the notch filters, but they are generally difficult because notch filters are generally for a specific filter frequency range.

So, if you have a specific peak at a particular frequency a notch here can work, but what if this frequency changes its position? What if the heartbeat changes? Then this is not effective. So, in such a case you need a little more involved type of an artifact removal algorithm.

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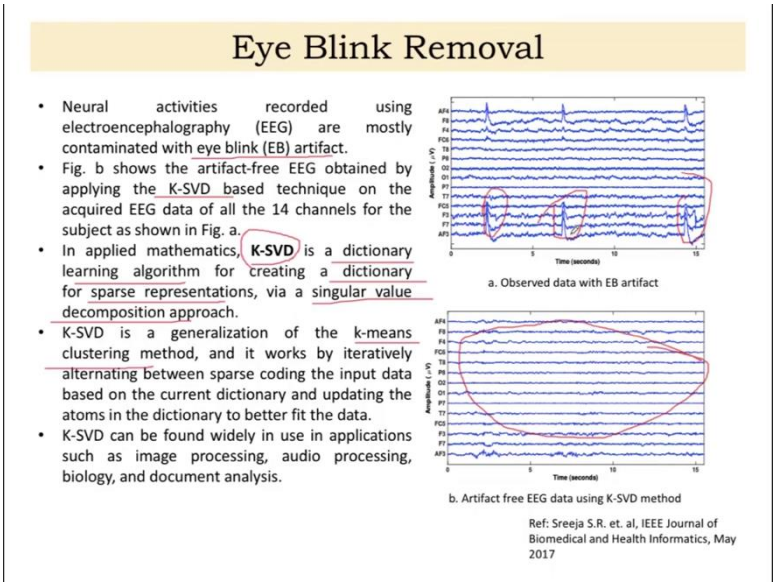

So, one of the algorithms that we use in such a case is called K-SVD algorithm which is particularly used for eye blink artifact removal. As you can see here that all the data in the 14 channels of a subject and even you can clearly see the eye blinks, you can clearly see and if you use a K-SVD which essentially works on a dictionary learning. It first learns this frequency nature of frequency of this and then you know it creates a dictionary for sparse representation using a singular value decomposition approach.

And, then this K-SVD actually is based on a k-means of a clustering method, that works iteratively on each one of these signals and make a best fit and then it gives the filter data. So, this is what becomes the filter data where this entire artifacts are absent.

So, this needs some algorithms to work now luckily most of the EEG comes with software and these software's will be definitely having K-SVD as one of the popular option which can take care of this. But, you need to know that this kind of a filtering needs to be applied for things like eye blink removal.

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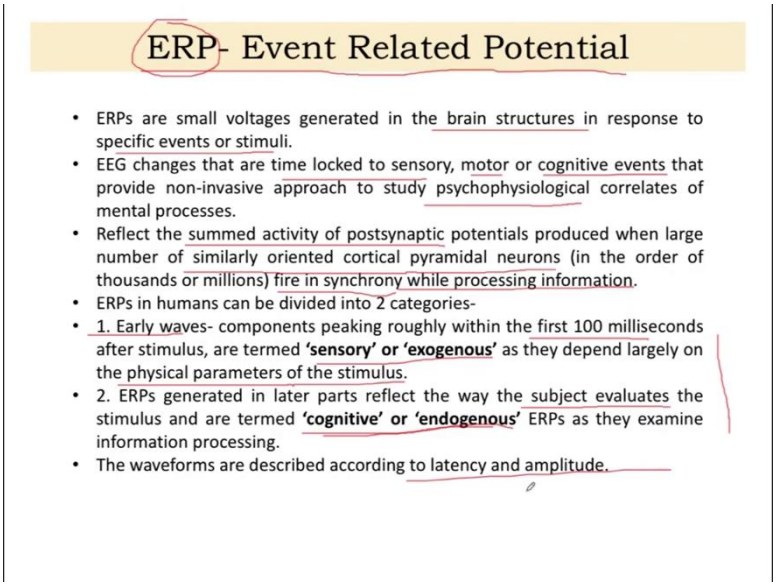

So far we have discussed about the ambient signal that is anytime if you place an EEG on the brain what are the signals that will be coming out and how you can take out the artifacts noises etcetera from it.

Now, we will look into that if you give a specific stimulus to the brain, let us say you give me a task to actually play a game or to count a number or semi such any such tasks then actually the external stimulus comes into picture and then there is something called event related potential that we can measure from this signal that is what we will be discussing now.

So, now, we will be talking about event related potentials or in short ERPs. These are small voltages that is generated in the brain structures when you are subjecting it to specific events or stimuli. Now, EEG changes that are time locked to sensory motor or cognitive

events that provide non-invasive approach to study these psychophysiological correlates, this is where the ERP is actually very important.

So, it essentially reflects the summed activity of postsynaptic potentials produced when large number of similarly oriented cortical pyramidal neurons in the order of some thousands or millions of neurons will fire in synchrony while processing the information and this ERPs can be divided into two categories.

Early waves – components peaking roughly within the first 100 milliseconds and they are termed as sensory or exogenous as they depend largely on the physical parameters of the stimulus. And, then the cognitive or endogenous ones which is after 100 millisecond or 200 millisecond as the subject evaluates the stimulus, then the reflection of that comes in the form of cognitive or endogenous signals.

So, you see both of them are important for us from a cognitive robotics point of view and this waveforms are described according to their latency that when they are appearing and their amplitude.

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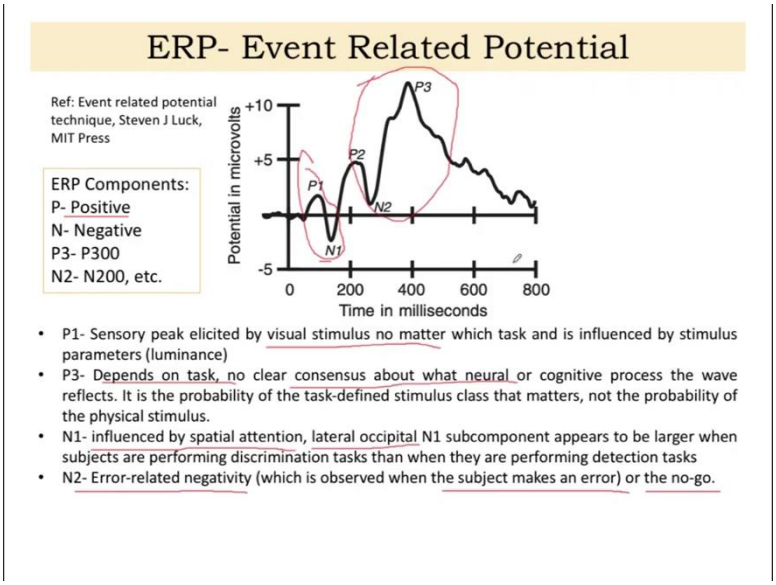

So, these are some of the common ERPs as you can see here that Ps are the positive part of the ERP in the signal and then there are negative parts also. So, early part within 100 millisecond you will get you will expect P1 N1s and beyond that you are getting P2 N2 and P3s. So, this is what is in the later part that you will be getting into the system.

So, P1 sensory peak which is elucidated by visual stimulus. P3 depends on task and there are still some debates that what is the exact reason some people think that you know it comes because of a specific type of a response particularly error related responses etcetera.

N1 is influenced generally by spatial attention and N1 is generally obtained from lateral occipital regions. N2 is the error related negativity which is observed when the subject makes an error or the no go. So, this is where N2 comes into picture and to some extent P3. So, this is what is the ERP or the Event Related Potential.

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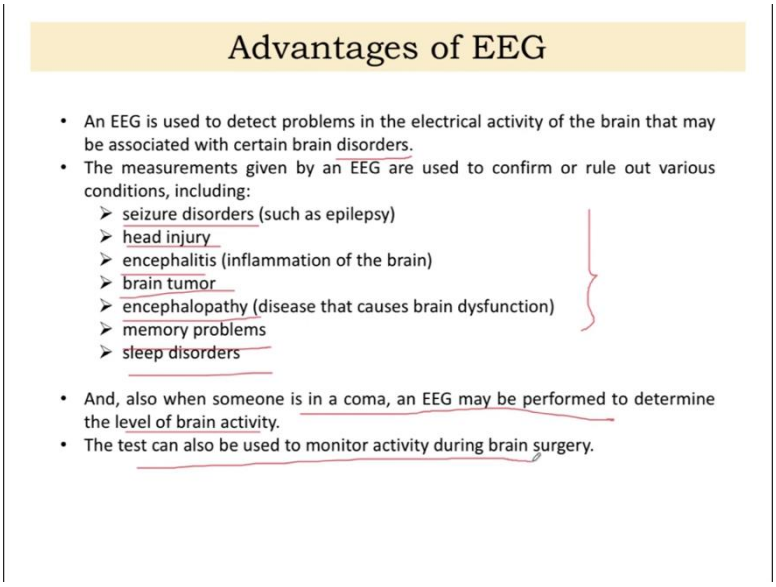

Now, what is the advantage of this EEG? Well, first of all it is a non contact way of judging the level of the brain. It is also useful during disorders not just a general brain condition like seizure disorder, head injury, encephalitis, brain tumour, encephalopathy, memory problems and sleep disorders. All these cases the EEG becomes a very very useful tool.

Also, when someone is in a coma, an EEG may be performed to determine the level of the brain activity. And, the test can also be used to monitor activity during brain surgery. So, there are many usage of the EEG.

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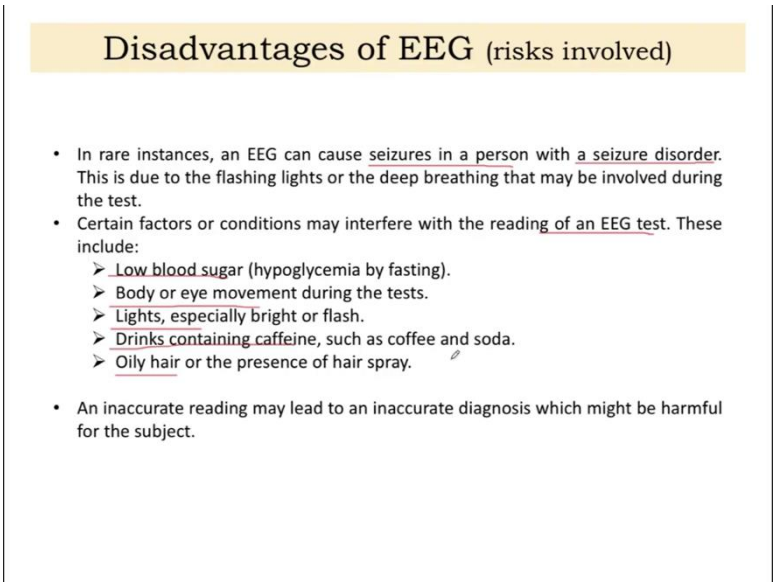

What are the precautions? Well, first of all EEG in very rare circumstances can cause seizures in a person who has already a seizure disorder. So, that is something that you know is generally it is very rare.

Now, certain factors or conditions that may interfere with the reading of an EEG are low blood sugar, body or eye movement, lights, drinks containing caffeine I already told and oily hair that is why they say do not apply shampoo on the hairs. So, this is all that we have to keep in our mind for a successful EEG test.

So, these are the points that we have to keep in our mind for an EEG test which is very important for brain computer interfaces.

Thank you.