Introductory Neuroscience and Neuro-Instrumentation
Professor Hardik Pandya
Indian Institute of Science, Bengaluru
Lecture - 10
Fundamentals of EEG and Applications

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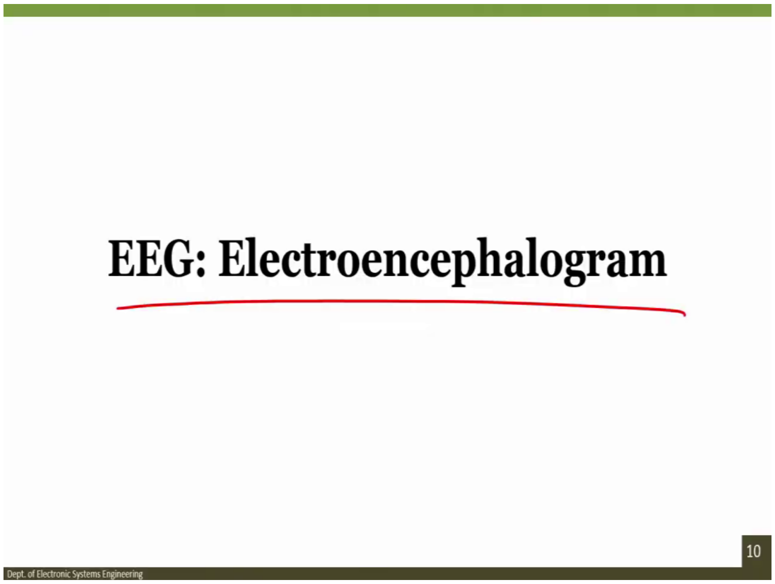

Now, let us talk about the problem which we are focused on in this course and that is your EEG signal, which is an electroencephalogram.

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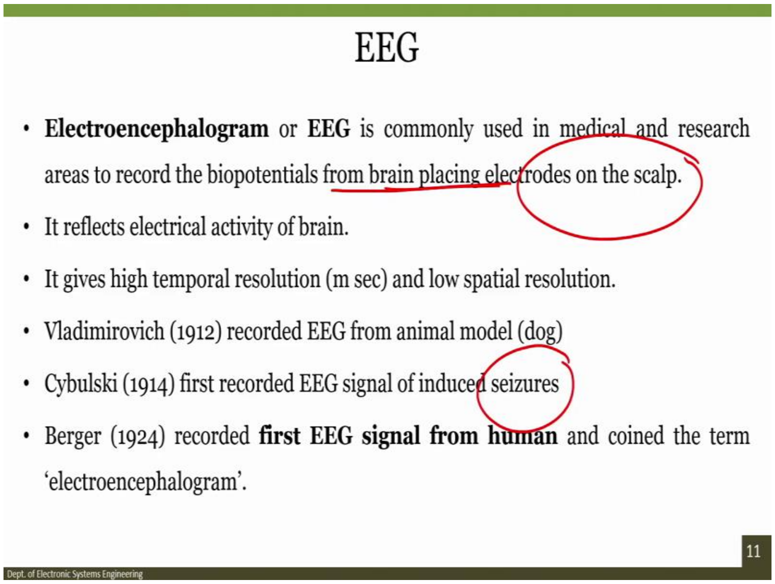

EEG or electroencephalogram is commonly used in medical and research areas to record the biopotentials from the brain placing electrodes on the scalp, on the surface of the scalp. What exactly we get from EEG or how it is measured, how it is generated?

It is generated because of the electrical activity of the brain. It gives a high temporal resolution for milliseconds and low spatial resolution. Vladimirovich in 1912, recorded EEG from the animal model, which is a dog.

Cybulski in 1914, first recorded EEG signals of induced seizers, seizers mean nothing but epilepsy, we will discuss this in detail. While Berger in 1924, recorded the first EEG signal from a human and coined the term electroencephalogram.

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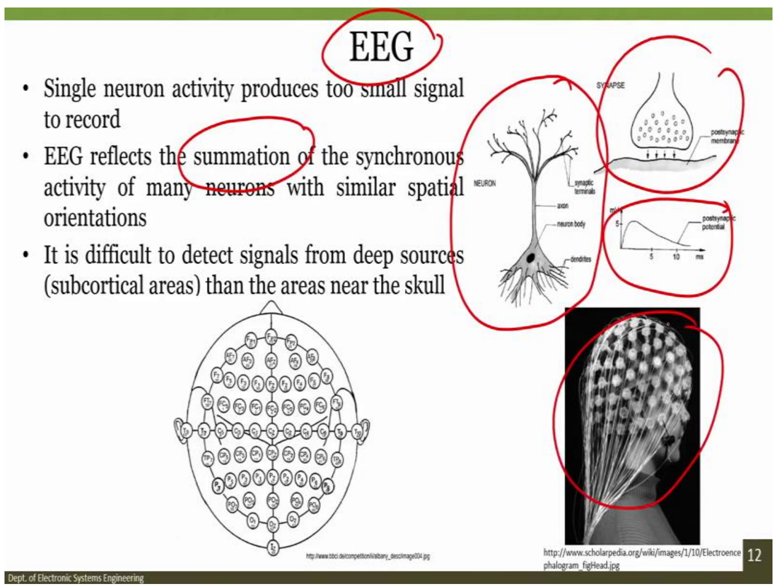

So, we discussed in previous modules what are these FC, frontal lobes and occipital lobes, and parietal lobes, and temporal lobes we discussed that. We also discuss a 10-20 system so that there is uniformity in the placing of the electrodes immaterial of the size of the brain or the head size.

So, EEG is a single neuron activity that produces too small a signal to record, or how EEG is measured? EEG is some of the signals generated by multiple neurons because single-neuron activity produces a too small signal. Second, EEG reflects the summation as I said, the summation of the synchronous activity of many neurons with similar spatial orientations. It is difficult to detect signals from deep sources in subcortical areas than the areas near the skull.

So if you see a single neuron, what you will see? You will see dendrites, then you will see the neural body, you will see axon, and you will see sympatric terminals. While the synapse, it relates to the postsynaptic membrane. So you can see the signals like this, we will take in, in a new slide and we will understand further. You can see here the 10-20 system how it is connected.

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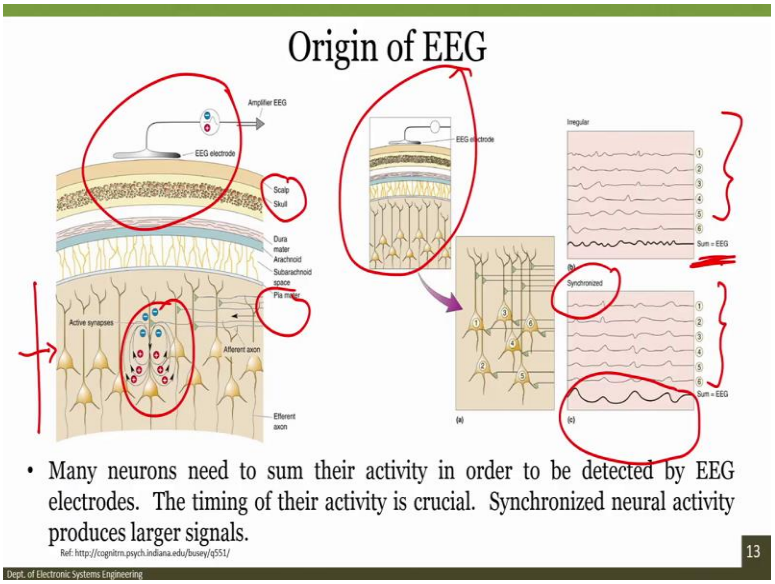

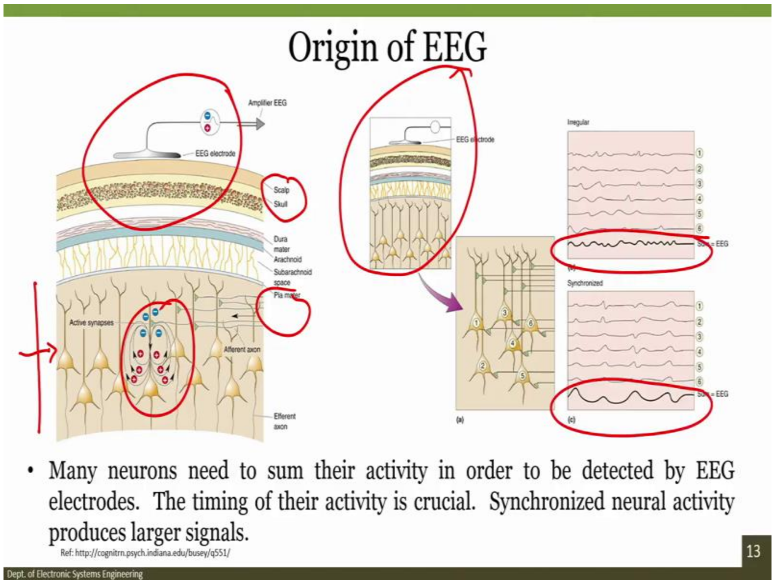

So, how the EEG signal is originated? So if you see here, this particular schematic, there is an afferent axon and there is an efferent axon. The effective synapses create a potential and the group of neurons, in a synchronized manner, the signal is transmitted through the pia mater through the subarachnoid space or arachnoid space, dura mater, all the way through the skull to the scalp and your EEG electrode. This is the group activity, and you can see the active synapses is how they generate potential.

So, in another way, if you want to see further, if this is the EEG electrode and this is the same schematic which is here but of a different size, then if I take this, the neurons, you can, if you number it 1, 2, 3, 4, 5, 6, and then we want to measure the signal from each neuron, you can see there is an irregular pattern, and there is a synchronized pattern.

An EEG is nothing but a summation of these patterns, the summation of the signals generated out of a group of neurons. So in the synchronized manner, you can see that it is a clear summation we can see the change in the activity. So many, many neurons need to sum their activity to be detected by EEG, the electrodes. The timing of their activity is crucial. Synchronized neural activity produces a large signal.

We can see here compared to the irregular EEG signal, when you sum it and when you take synchronized EEG signal and you sum it, the synchronized version produces or neural activity produces a large signal.

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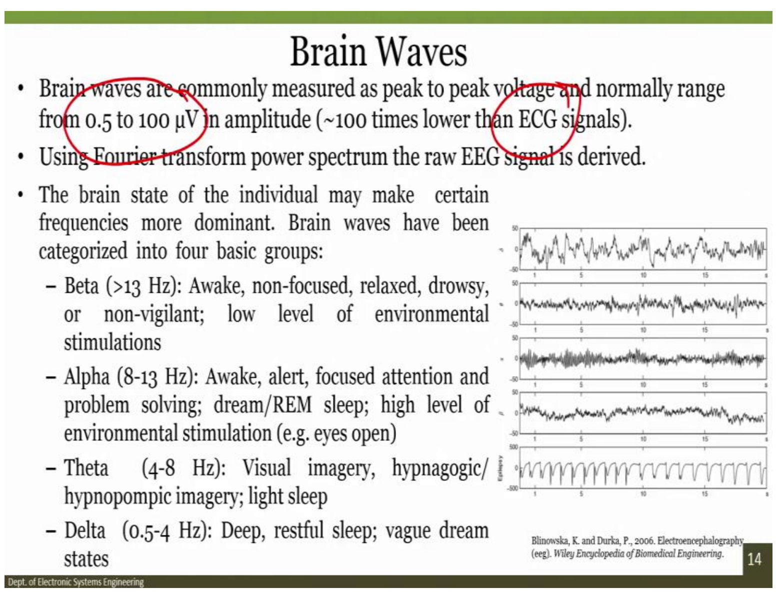

So now, we understand that by placing electrodes on the scalp, we can measure the brainwaves. So what are brainwaves? Brainwaves are commonly measured as peak to peak voltage and normally range from 0.5 to 100 microvolts in amplitude, which is approximately 100 times lower than the ECG signal.

You can see here, it is only a few microvolts wherein ECG, is about a few millivolts. So at least 100 times lower than EEG signal and that is why the difficulty will be when you measure this signal because you must take care of the noise interfering with your signal. So that is one thing.

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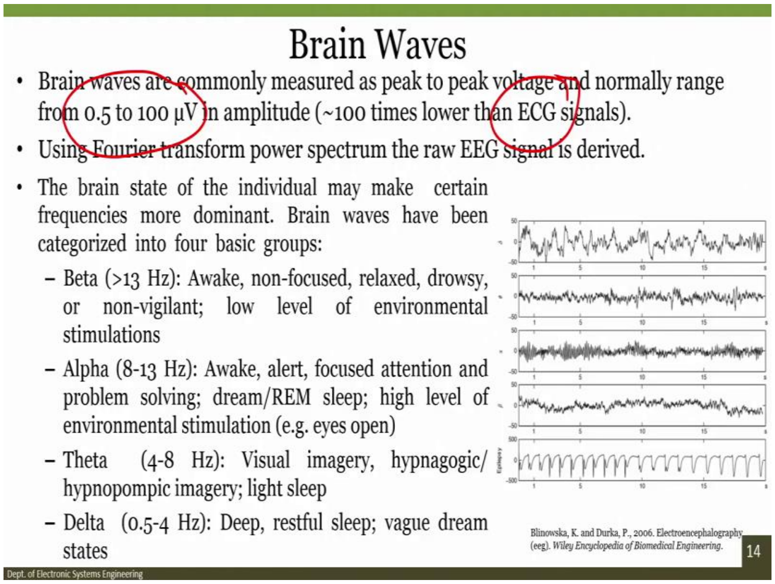

Using Fourier transform power spectrum, that raw EEG signal is derived. The brain state of the individual may make certain frequencies more dominant. So while brain waves have been categorized into 4 basic groups. So depending on the individual, the brain state would be different and certain frequencies would be more dominant compared to others.

So what are these frequency ranges? So based on the brain, the brain waves are divided into 4 groups and those 4 groups are beta, alpha, theta, and delta. Now, let us see each of those. The beta will show when you awake, non-focused, relaxed, drowsy, or non-vigilant low-level of environment stimulations. It is around greater than 13 hertz.

So when you are on, not dead, you are awake but non-focused then you are relaxed and drowsy and you are non-vigilant and then at that, and low-level of environmental simulation is there, then at that, the time beta waves can be measured using your EEG, EEG will show beta waves.

Alpha is 8 to 13 hertz. This is the alpha signal, you can see a pattern 8 to 13 hertz and these signals are awake, focused, attention, problem-solving, dream, REM sleep, high level of environmental stimulation. For example, eyes are open, you are talking, you are moving your eyes, you are in REM sleep or you are focusing attention, at that time you are alphas signals would be there.

While the theta is 4 to 8 hertz, theta is 4 to 8 hertz and visual imagery, and you have a light sleep or you are on hypnagogic imagery, at that time you will be able to see the theta waves. Finally, the delta, which is between 0.5 and 4 hertz shows a deep restful sleep, vague dream states. This is the delta.

So brainwaves are divided into 4 groups, you can say delta, theta, alpha, beta. Delta, deep restful sleep; theta, visual imagery; alpha, awake focused, alert; beta, non-focused, relaxed, drowsy. And this is the signal, EEG signal when the person is suffering from epilepsy. So there they are, these are the brain waves that we can divide into groups.

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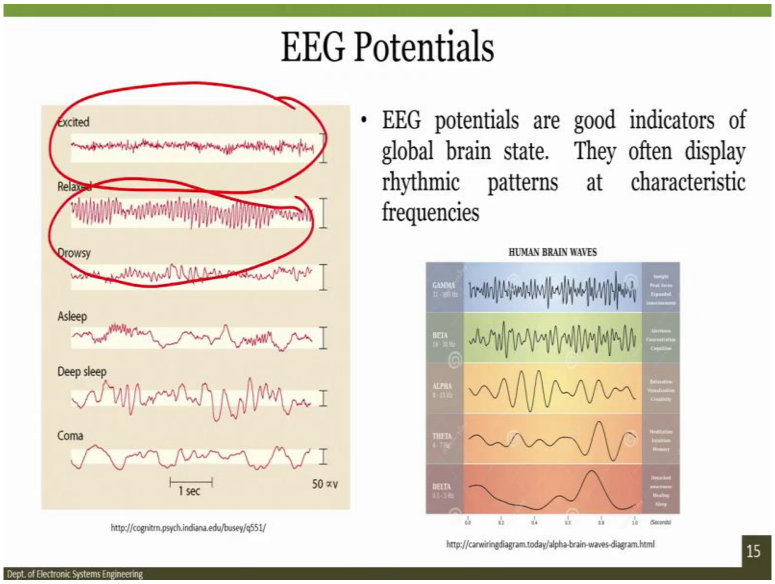

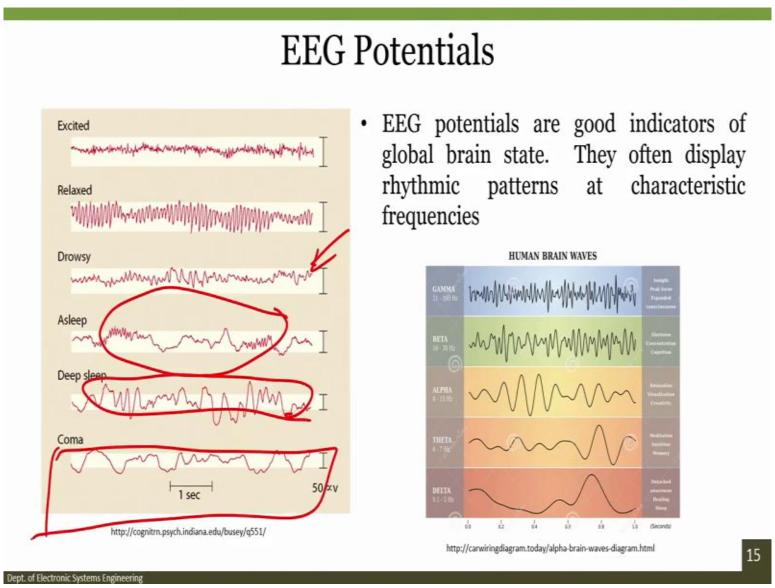

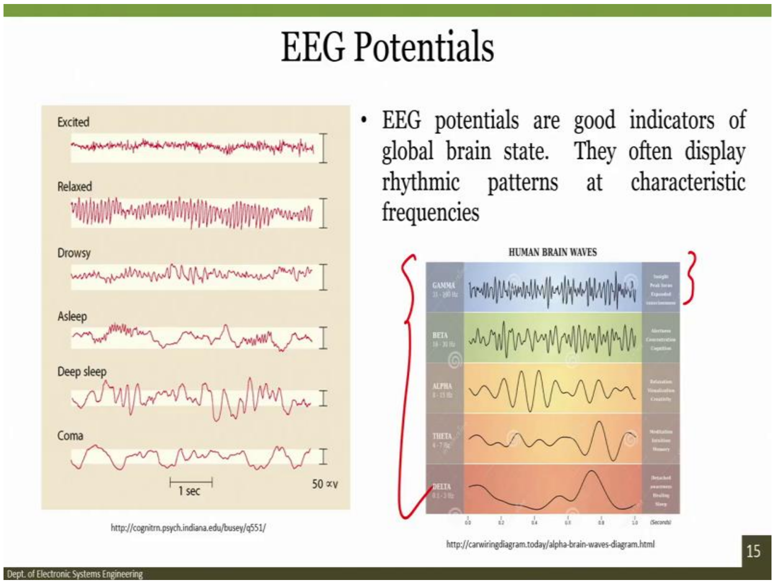

Now let us see, EEG potentials are good indicators of the global brain state. They often display rhythmic patterns and characteristic frequency. You can see excited, it will look like this; relaxed, then drowsy, asleep, deep sleep, and coma. All this frequency, we can measure or other patterns we can measure depending on the state of the brain.

The same thing is here again, right, gamma, beta, alpha, theta, and delta. A gamma frequency is there which is between 31 and 100 hertz also, and it shows the peak focus, expanded consciousness. It is very difficult to see the gamma frequency in the human brain waves. We require a deep focus insight and an expanded consciousness to see the gamma.

While the beta is alertness, concentration, cognition. Alpha, relax; theta, mediation, meditation, when you do meditation theta waves are there. And delta is a detached awareness, healing, sleep. These are the states of the brainwaves.

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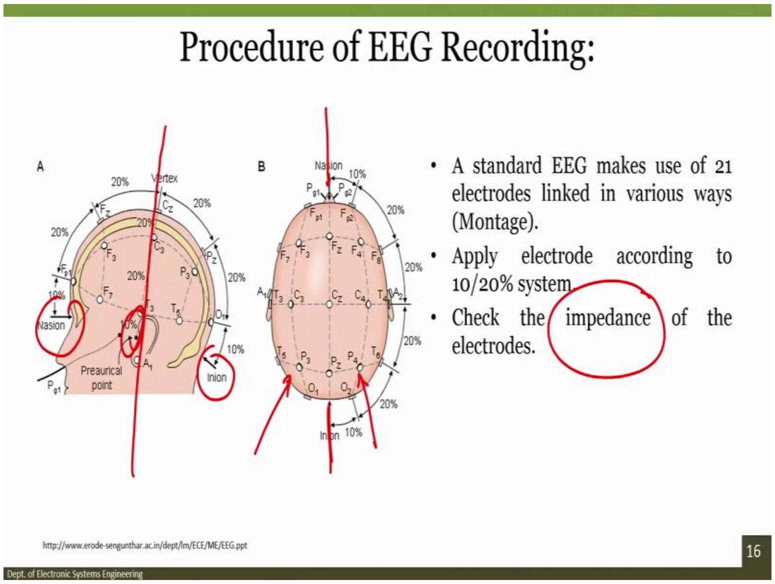

Now, there are the different procedure for EEG recording and as I said, if you divided it from the nasion, we see 10, 20, 20, 20, 20, and 10, and you read through the inion. From nasion to inion, this is how it is divided. I told you that on the right side it will be even number, and on the left side, it will be odd numbers.

So from nasion is this part and inion is this part. So, in another viewpoint, you can see the thing and that there is a preauricular point which is right over here. So if you say vertex and you take it then this is somewhere your preauricular point.

So a standard EEG makes use of 21 electrodes linked in various ways or montages, we can say. Apply the electrode according to the 10-20 system, check the impedance of the electrodes. Impedance is very important and to reduce the impedance, in wet electrodes we generally use the gel. For dry electrodes, impedance is already low.

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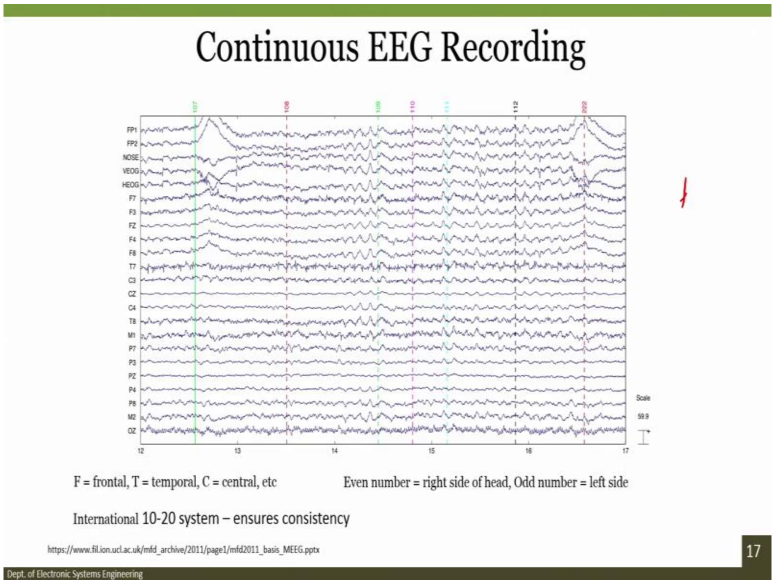

So if you have measured continuous EEG recording, from the EEG recording, we can understand if there is a problem with the brainwaves. Particularly, if you want to see kind of epilepsy and another phenomenon, the EEG recordings are done.

You can see the recordings from all these electrodes and, of course, you would already know F stands for frontal, T for temporal, C for central O, for occipital. And it is an international 10-20 system.

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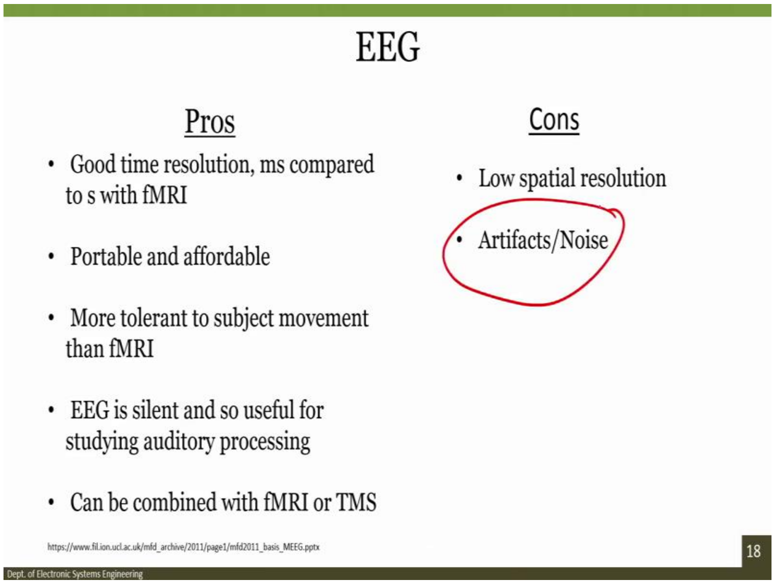

So what are the advantages of EEG and what are the disadvantages of EEG? The first advantage of EEG would be a good time resolution that is in millisecond compared to, compared with seconds which will be in fMRI. fMRI is functional magnetic resonance imaging or functional MRI. It relies on the fact that cerebral blood flow and neuronal activations are coupled.

So, when the area of the brain is in use, blood flow to that region also increases. This is the principle of fMRI. So it is a relation between the cerebral blood flows. Cerebral blood flow is a blood flow in the cerebra and the neuronal activity. So if more the blood flow that means activity is more, and activity is more there is more blood flow, so this is how it is calculated. But fMRI is a few seconds, while in EEG, it is only milliseconds.

Second is the EEG system is portable and affordable; in fMRI, it is difficult, more tolerant to subject moment compared to fMRI. EEG is silent and so useful for studying auditory processing, can be combined with fMRI or TMS.

The difficulties or disadvantages or limitations of EEG are low spatial resolution, and their artifacts and noise will cause the distortion in the signal, so you should have a conditioning, electronic conditioning modules which are of very high signal to noise ratio and good quality. So let us see 3 videos now for the EEG and brainwaves. I will play one by one.

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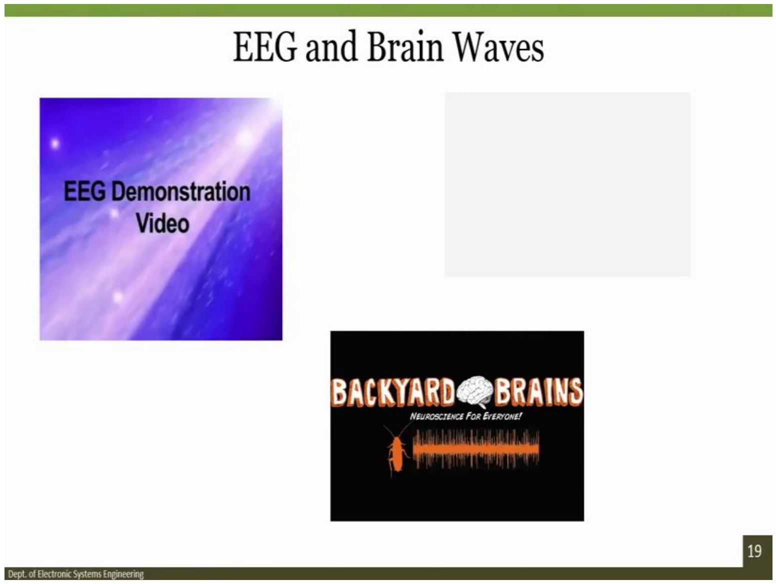

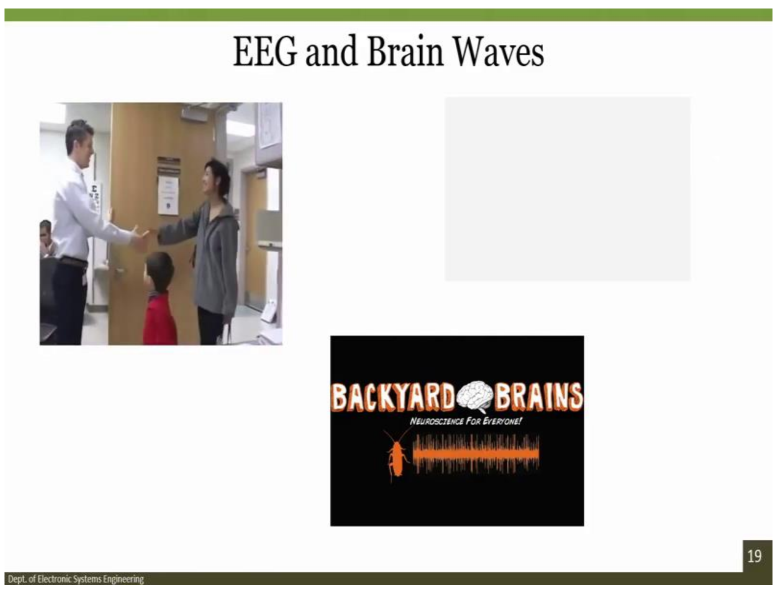

Narrator 1: When you arrive for your ERP session, you will be greeted by Frank and Nate. You can play with Nate while your family talks with Frank and reads about the study.

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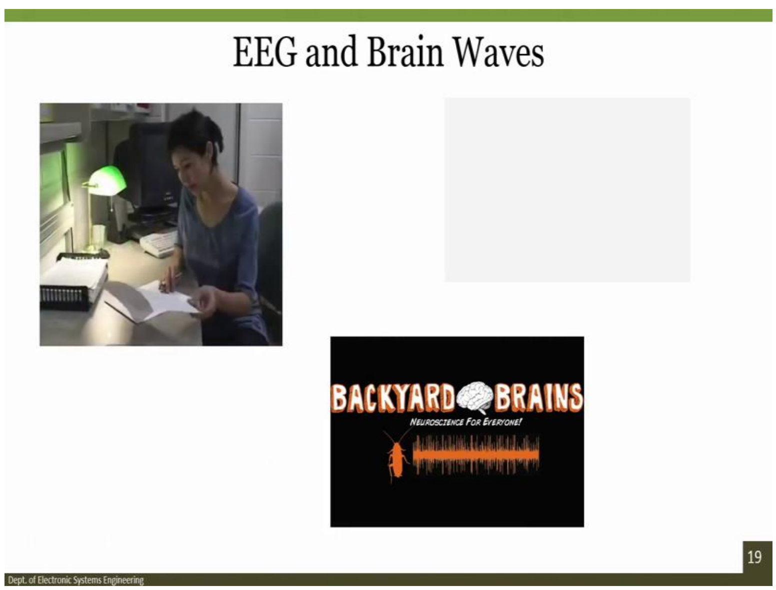

Narrator 2: It was great to see that Charlie was comfortable playing so that I was able to talk to Frank and read about the study.

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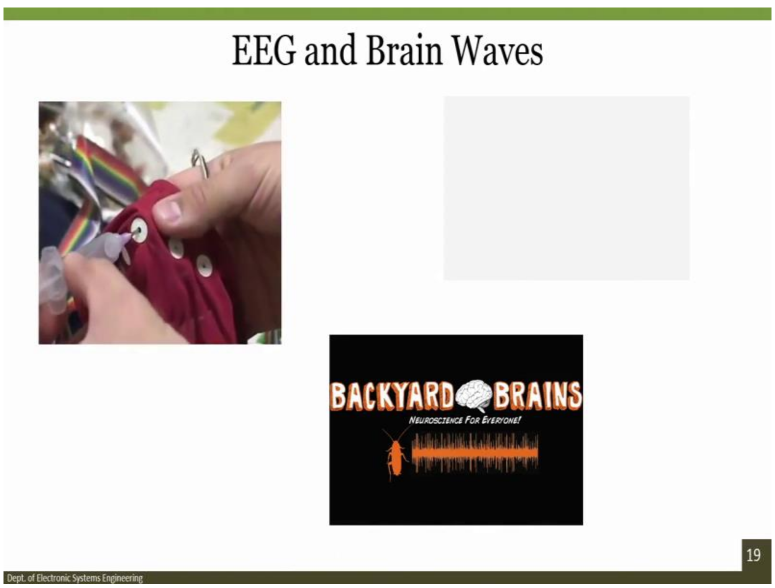

Narrator 1: While you play, Nate will show you the caps that you will wear during the study. They are stretchy and have lots of little holes in them. He will show you the syringe that he will use to help him get the cap ready.

It looks like something that you might get a shot with, but it is not sharp at all and it will not hurt you. It is only used to put some sticky gel into the holes in the cap. You will be able to put a cap on yourself and play with the syringe. That way, you will know exactly what will happen when Nate puts the cap on you.

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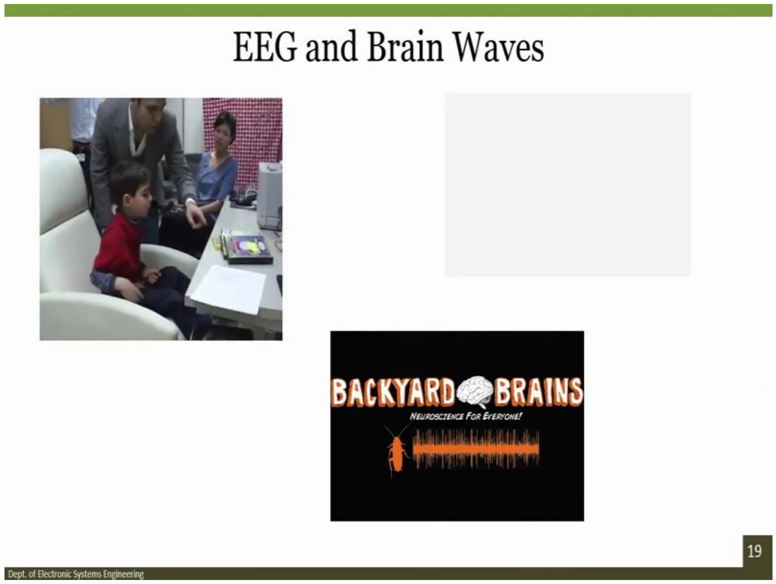

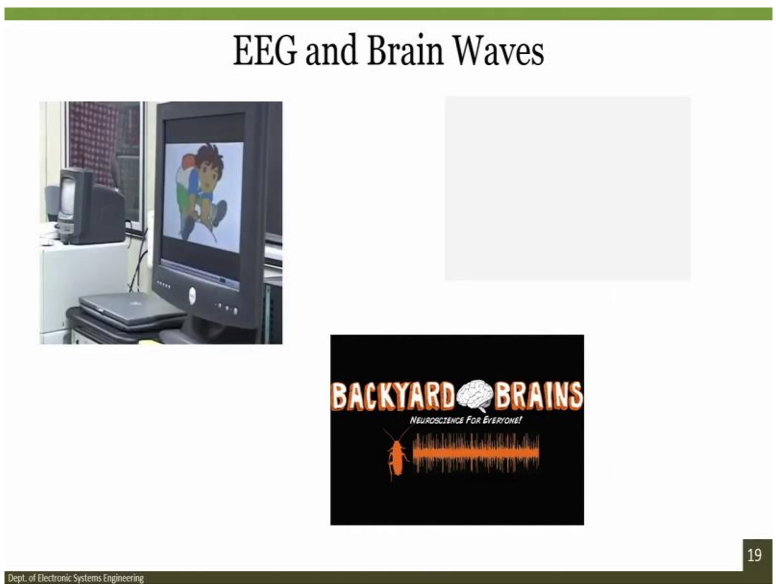

Narrator 2: Nate let him touch the syringe so he would know that it was not sharp or scary. It also helped prepare him for seeing it again later when it was his turn. When playtime is done, you will sit in a big white chair and pick out some cartoons you would like to watch. You will get to watch the first cartoon while Nate gets you ready for your cap.

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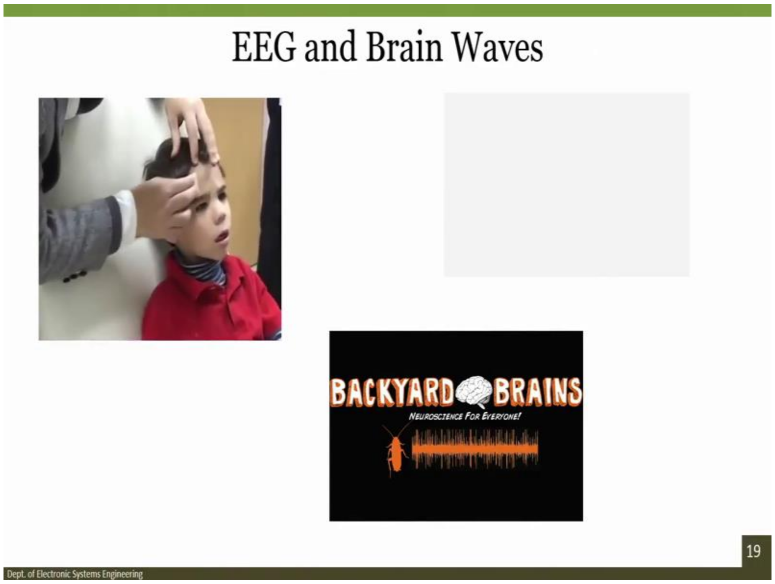

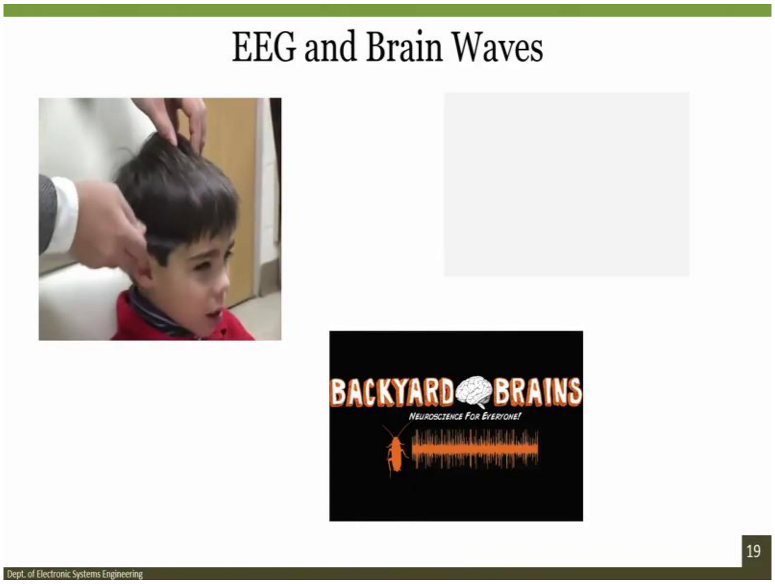

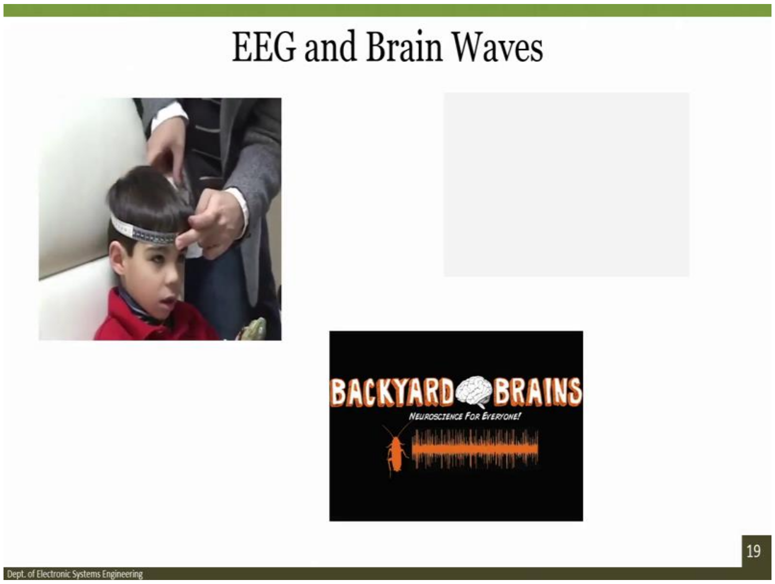

First, he will have to clean around your eyes and behind your ears with a wet cloth. Next to brush your hair and measure your head to be sure exactly which cap will fit you best.

Narrator 2: It was nice to get to sit right there with him so that I could see what was going on and be there if he needed anything.

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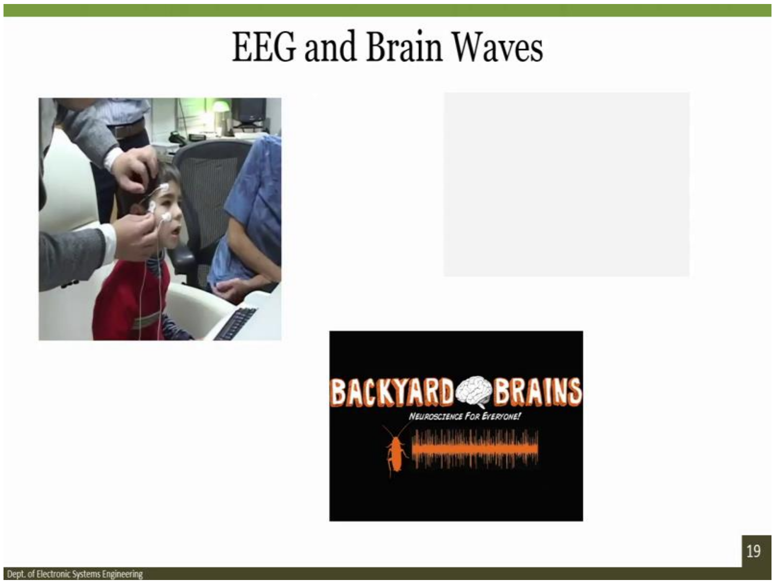

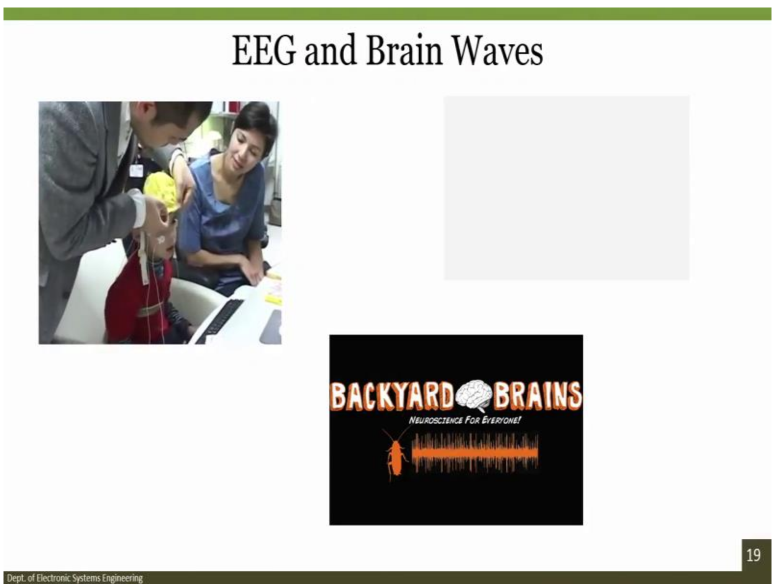

Narrator 1: Before he puts the cap on your head, he will put a few wires on your face with some stickers. When he is done with the stickers, he will put the cap on your head.

Narrator 2: While they were putting the cap on, they explained the different steps so that nothing came as a surprise.

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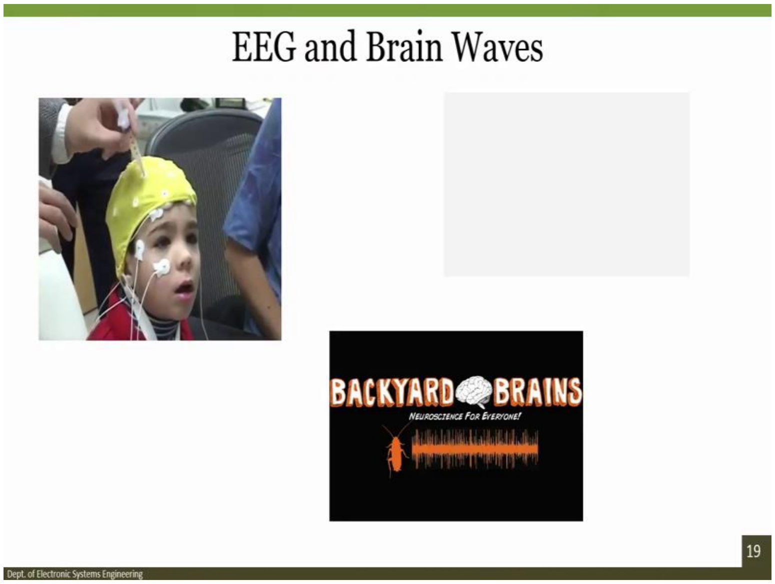

Narrator 1: Then, using the syringe he showed you during playtime, he will put some cold gel in each one of the holes in the cap. After there is gel in all the holes, you will go into the little room to watch a video that you selected earlier. You can ask your mom or dad to come with you into the little room if you would like.

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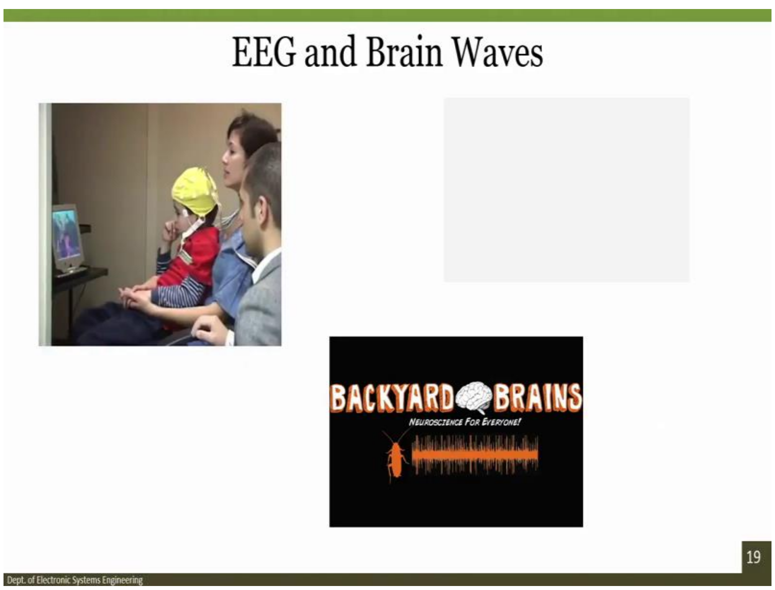

Narrator 2: I got to go into the sound booth with him which helped him feel relaxed. I thought it would be hard to help them stay still. But the room was calm and quiet. And we just sat and watch cartoons.

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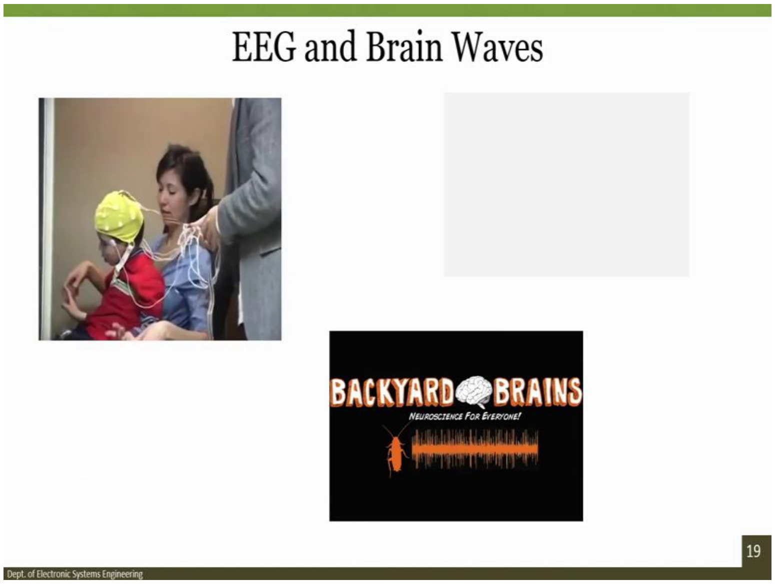

Narrator 1: Inside the study chamber, it is dark and quiet, and you will get to watch another cartoon. While you are watching this cartoon, it is important to be very still and very quiet. After you are done watching the cartoon, the cap and stickers will be taken off.

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Narrator 2: They took the cap and stickers off and told him what a great job he did.

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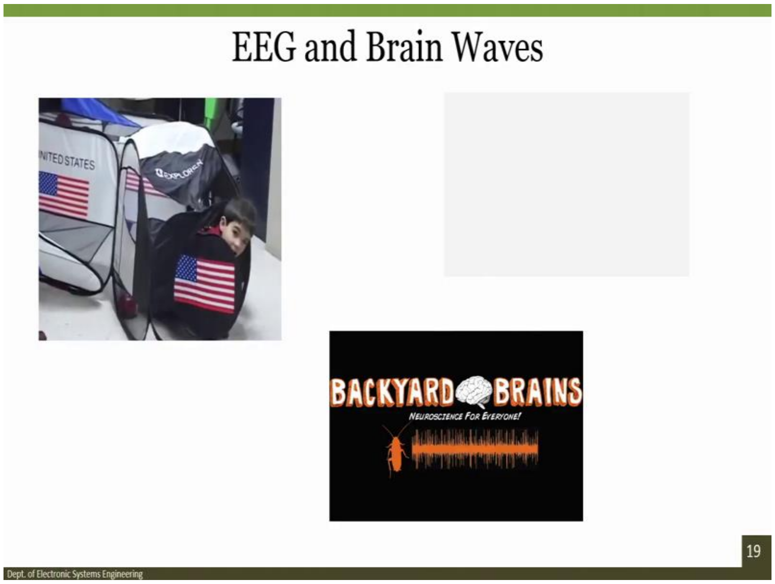

Narrator 1: When that is done, you will get to play and have fun in the lab spaceship.

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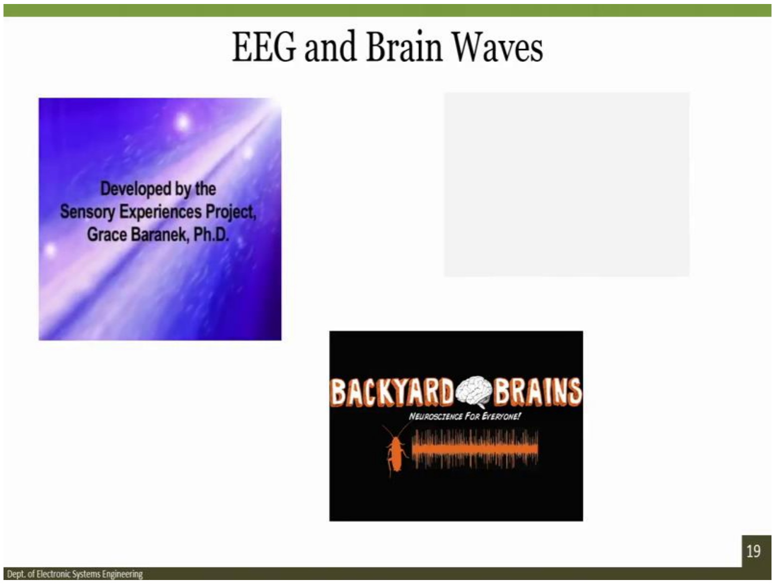

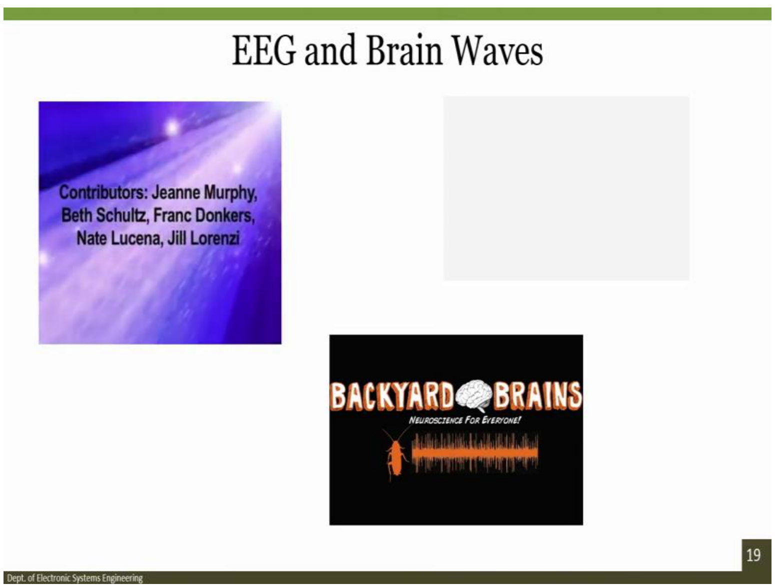

Narrator 2: Charlie thought all the equipment was cool, but I think his favorite part was getting to climb into the spaceship at the end. Thanks to their patience and care and explaining the process it was a great experience.

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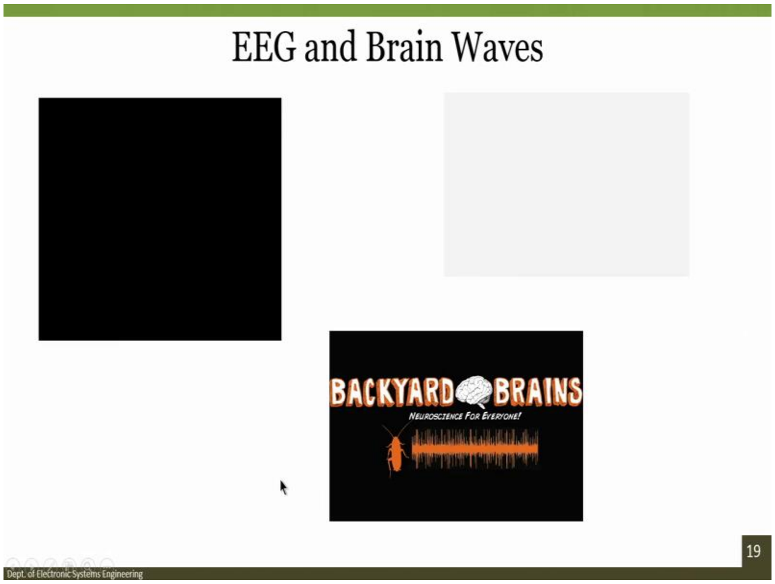

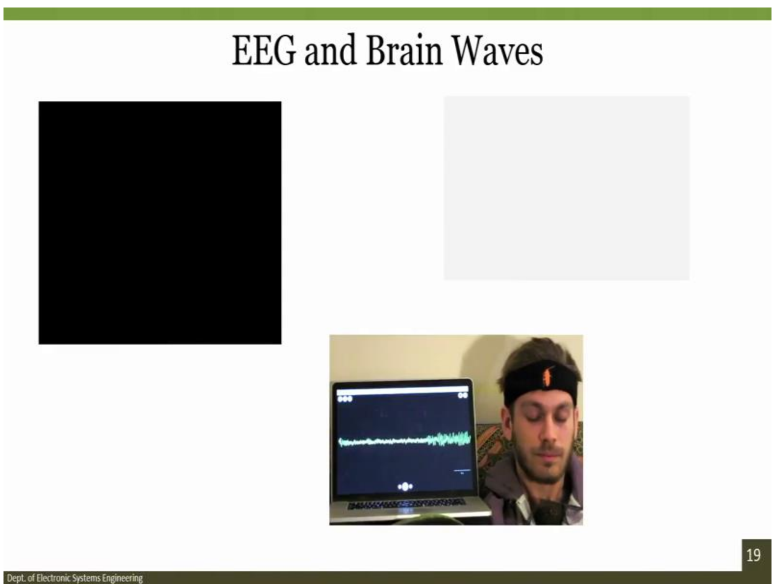

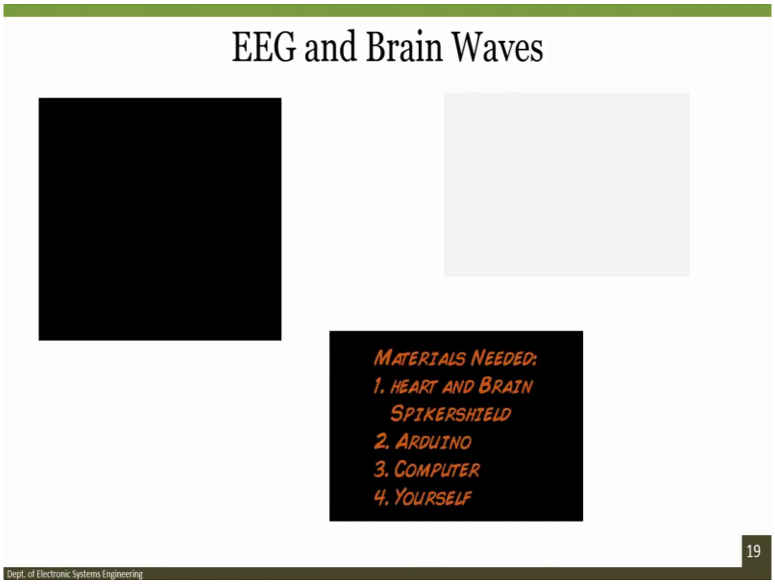

Backyard Brains presents the electroencephalogram, also known as the EEG. Observe the alpha waves of the visual cortex of the human brain. For this experiment, you need a heart and brain spiker shield, an Arduino, a computer, and yourself.

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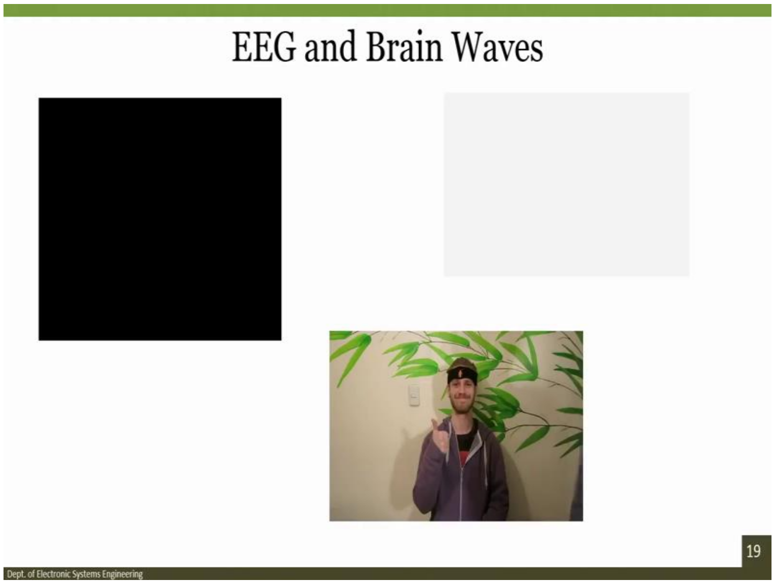

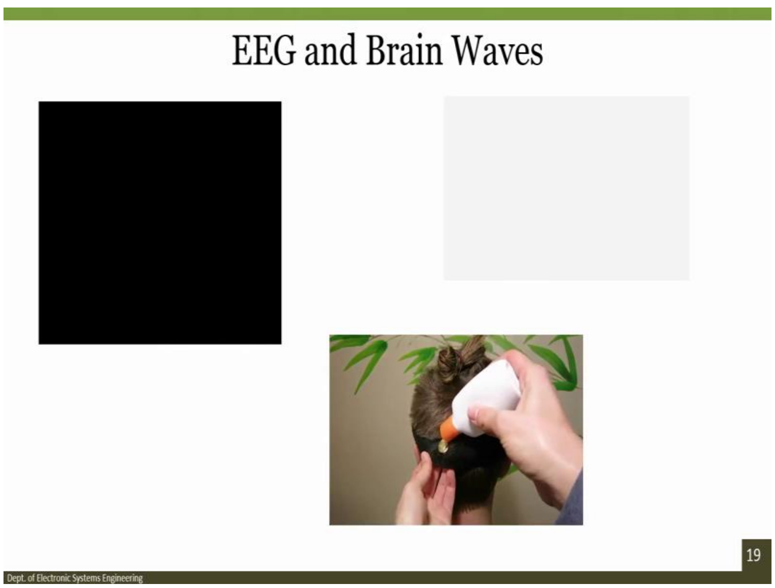

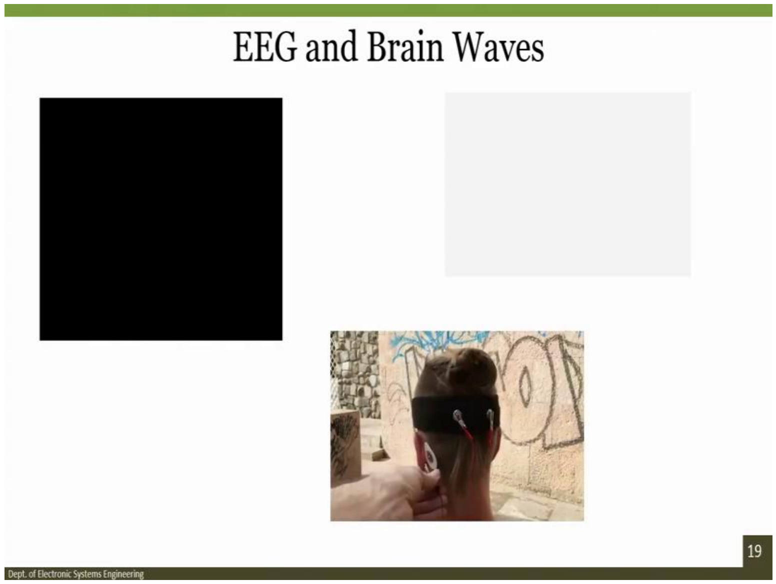

To be in, take the backyard brains custom EEG headband and place it on your forehead subset the electrodes on the back of the headband are located on the back of your head. For the ground, we will place an adhesive electrode on the mastoid process which is the bony projection you can feel behind your ear.

To improve the interface, we will play some conductive gel between the electrode and the skin. If you have long hair, you can pluck the hair directly underneath each electrode to further improve the quality of the signal. With your orange interface cable, attach the red alligator clips to the electrodes on the back of the head, which is which does not matter, and the black alligator clip to the ground behind the ear.

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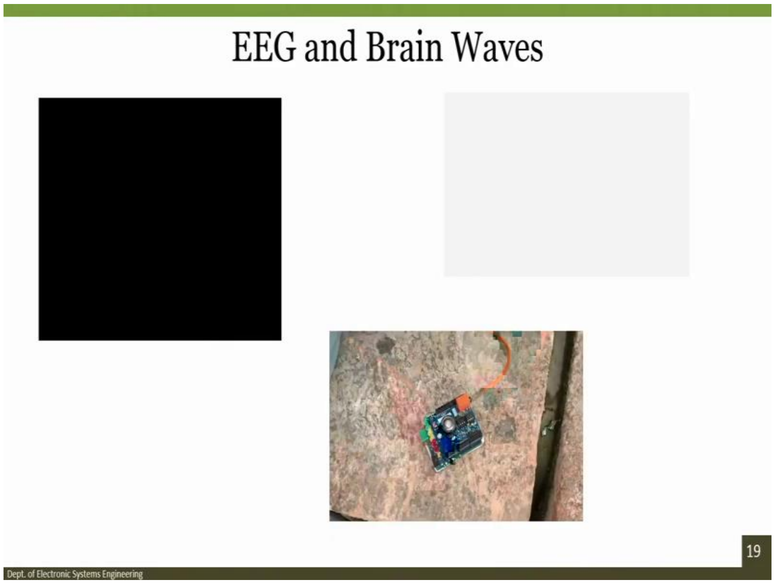

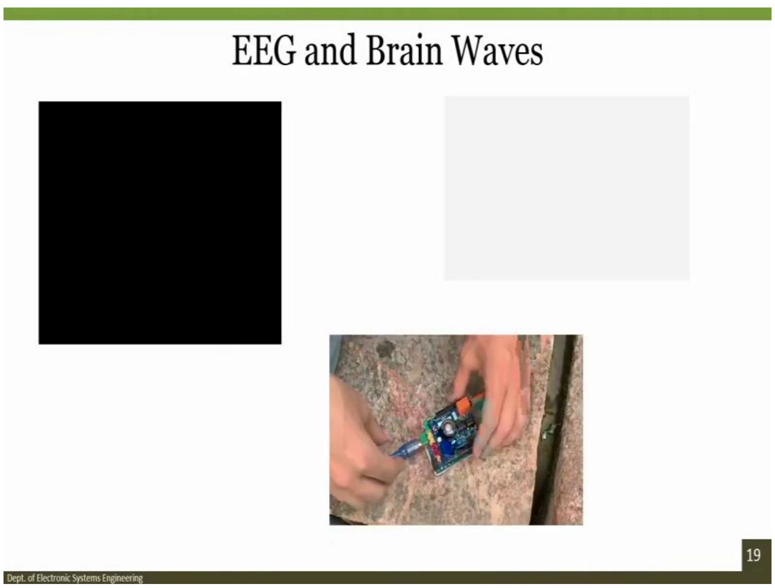

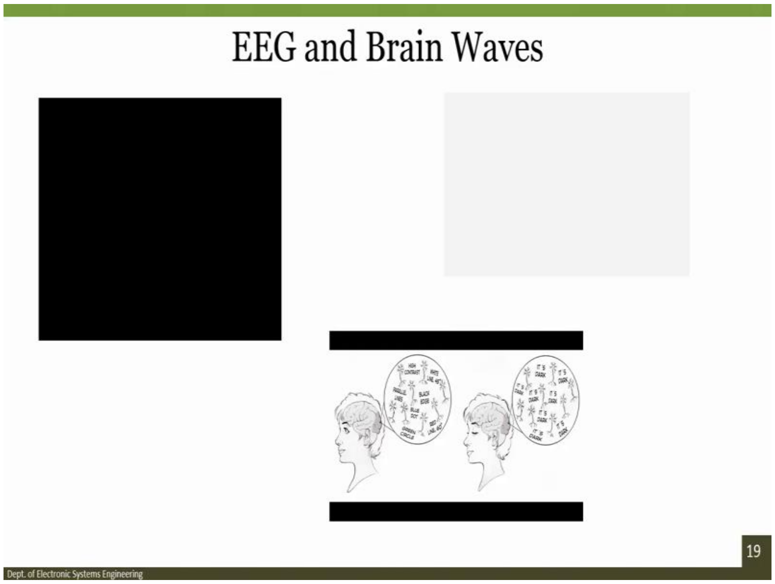

We then plug the orange cable into the orange port on the hardened brain spiker shield and the USB cable on the other side. The other end of the USB cable goes into the computer and we are ready to begin. But what is going on here?

When your eyes are open, the visual cortex in your brain is processing a lot of information about your entire visual field. About levels of contrast, color, and light. But when your eyes are closed, the field is dark, and hence counter-intuitively, the neurons in the visual cortex become more synchronized.

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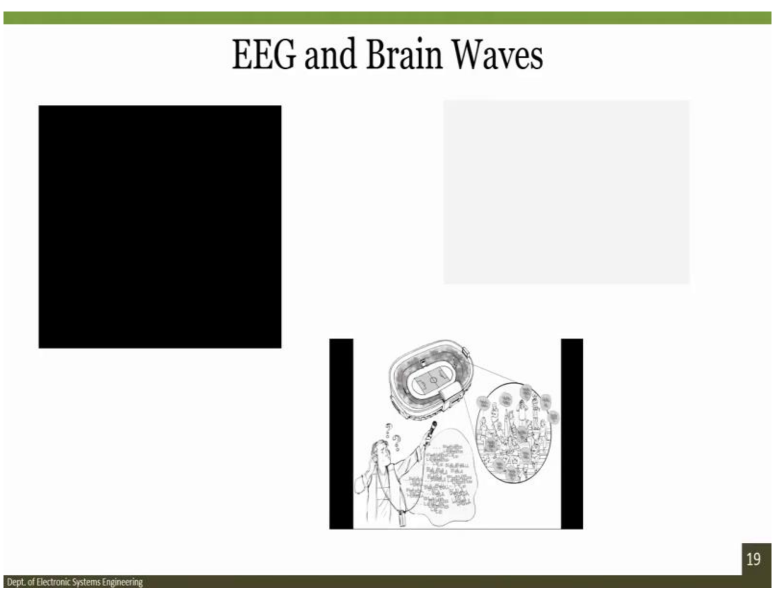

A popular analogy is to imagine yourself outside a stadium during halftime. There are a lot of conversations occurring inside at the stadium, a lot of information processing, but outside the stadium, all you hear is a dim hum of noise. This is equivalent to the eyes-open condition in the electroencephalogram.

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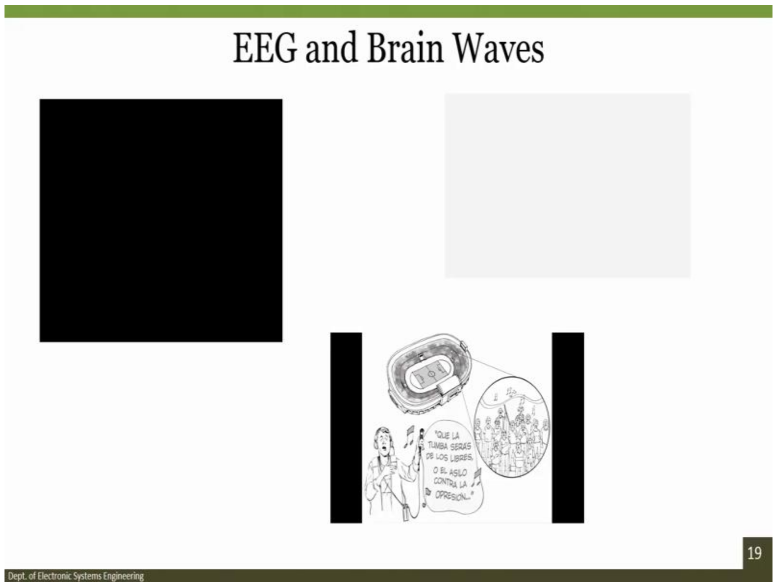

Alternatively, during the singing of the National Anthem, many of the spectators inside the stadium are singing the same thing. They are synchronized and this signal is strong enough that you can hear, though distorted, outside of the stadium. This is equivalent to the eyes-closed condition of the electroencephalogram.

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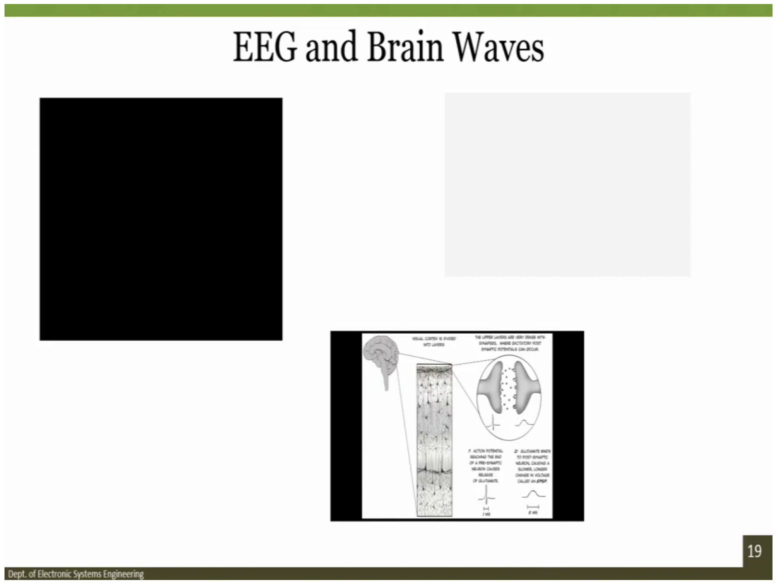

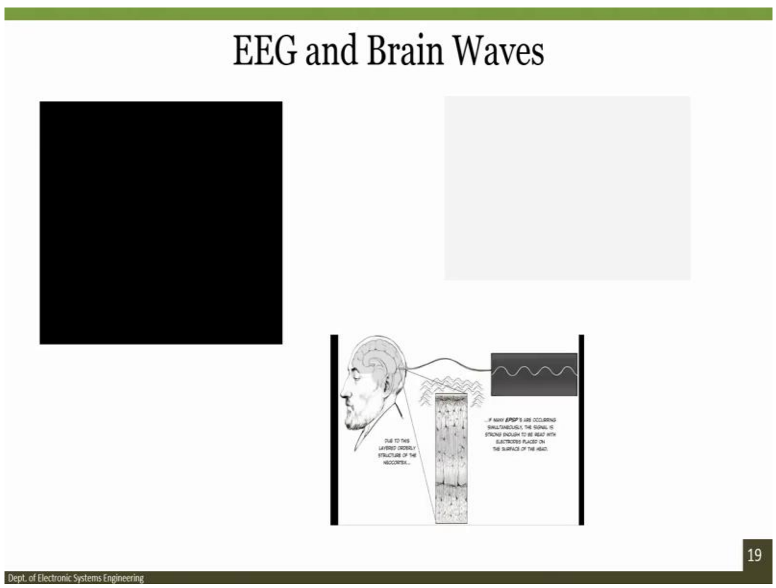

The physiological underpinnings of the EEG signal are complex and still a topic of active investigation in the neuroscience community. But we currently understand it to be at least some activity of many synapses in the upper layers of the cerebral cortex.

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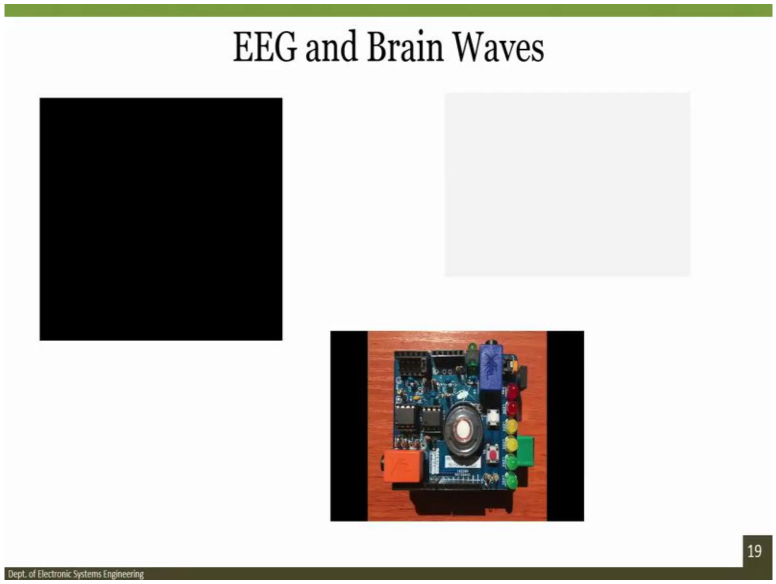

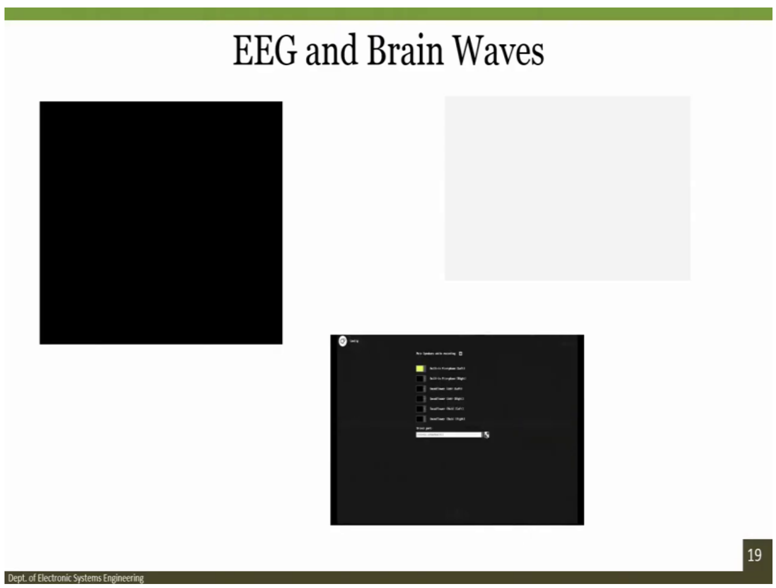

Our heart and brain shield thus amplify the electrical activity of these synapses such that we can view them on a computer under the appropriate conditions. Click on the settings button in our spike recorder software and select “Connect via USB port”. Within a couple of seconds, you should see the signal change to a putative EEG signal.

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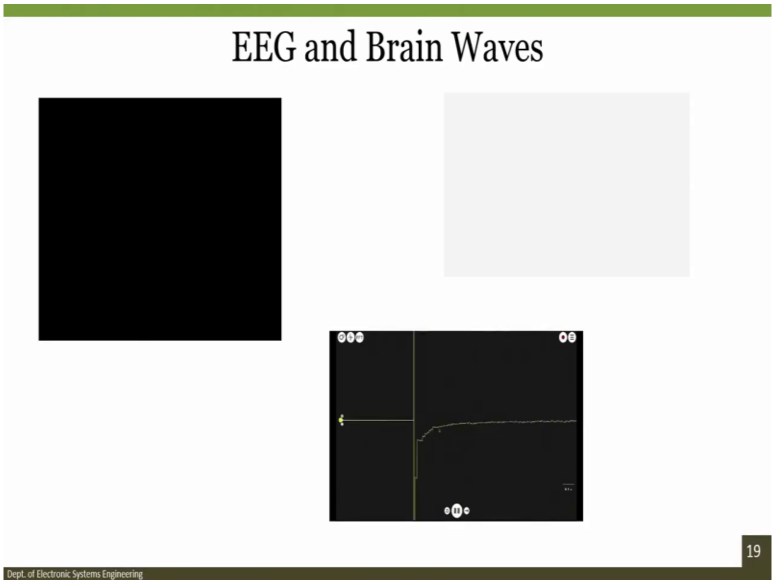

You can zoom out of the timescale by using the two-finger motion on your trackpad or the scroll wheel on your mouse and zoom in on the y-axis by clicking on the positive button on the left side of the screen.

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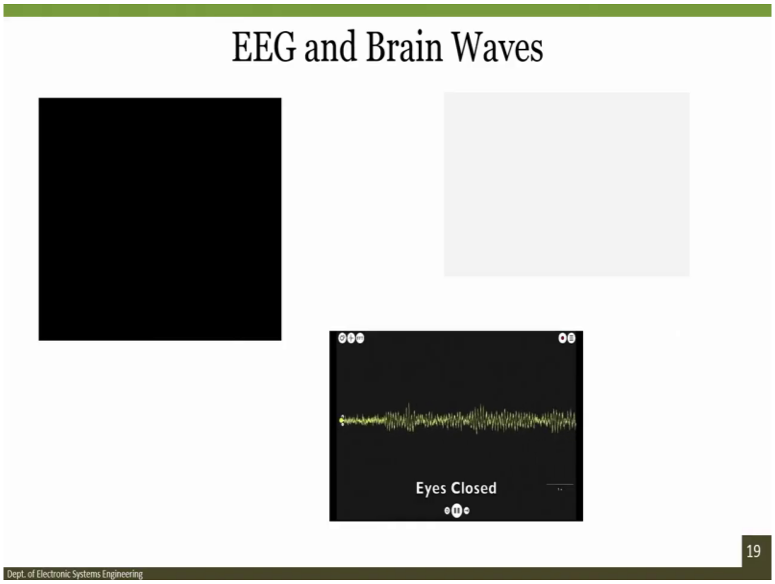

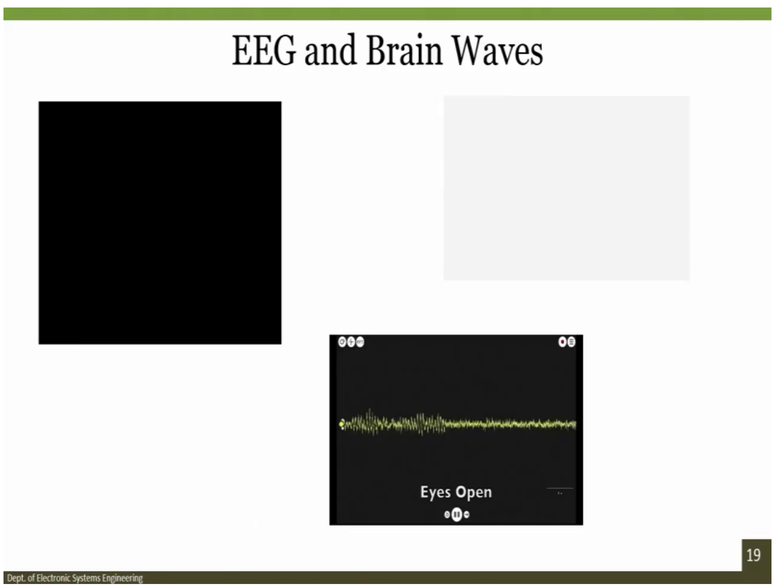

But how do we know this EEG signal is real? Well, let us close our eyes. Those ripples are the 8 to 10-hertz alpha waves of the visual cortex that disappear when the eyes open again.

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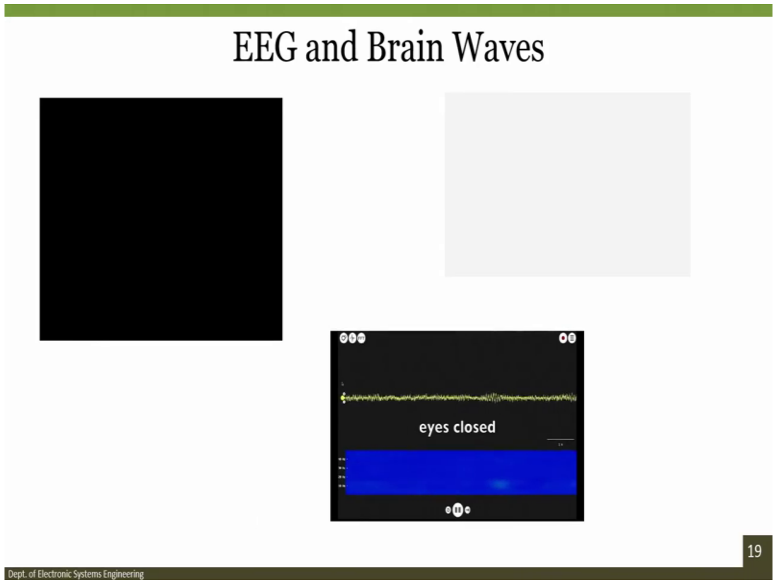

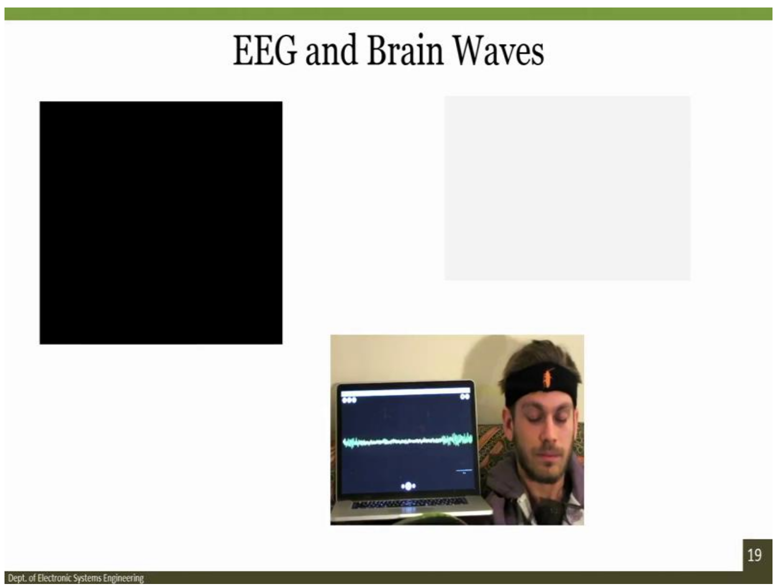

If you click on the FFT button, you will bring up a spectrogram view which will show the EEG signal decomposed into frequency time and amplitude. Thus, when the eyes are closed, you will note that the increased signal strength at 8 to 10 hertz.

Under appropriate conditions, the alpha waves of the visual cortex are readily apparent, whether you are showing them to your friends on a Friday night in your living room, or in front of 200 people for your high school or college lecture course.

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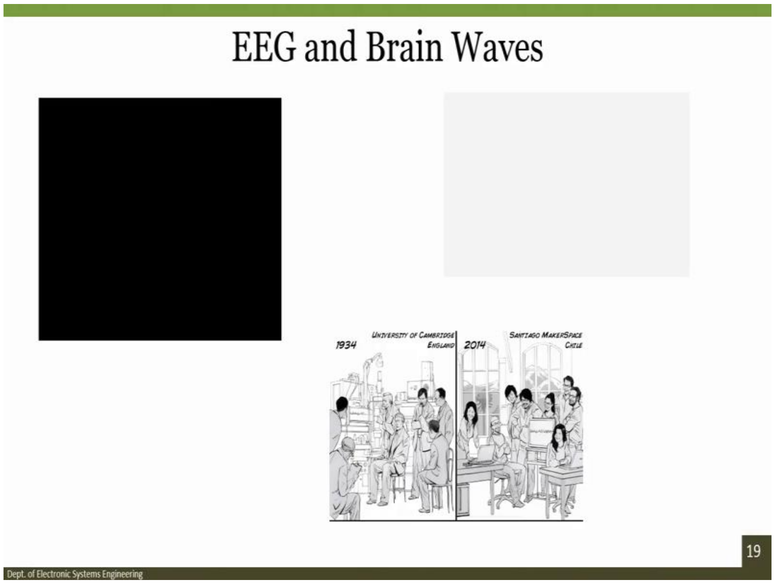

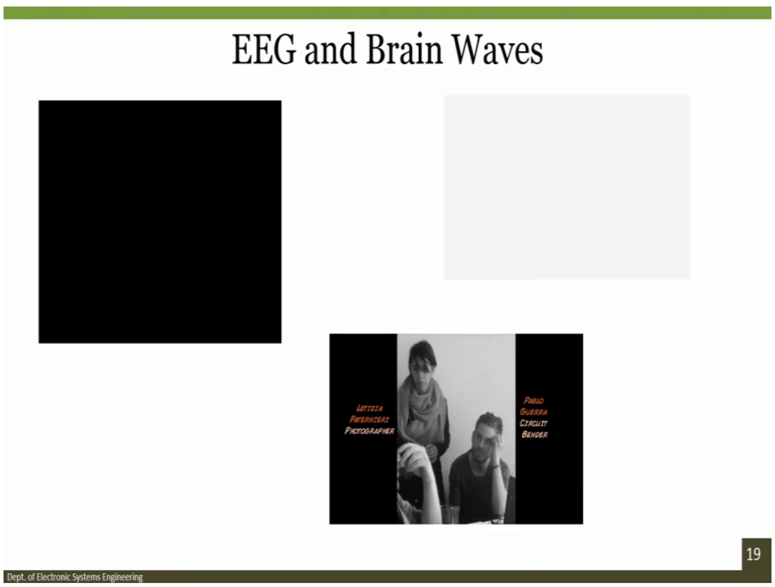

These alpha waves were first discovered by Hans Berger, a German physiologist in the 1920s, and subsequently verified by Lord Edgar Adrian at the University of Cambridge in the 1930s.

We thank our many friends at the Santiago maker space in Chile, who worked with us to replicate these findings compellingly and simply. We also thank our production team, and this is just the beginning as we further our explorations into the EEG signal.

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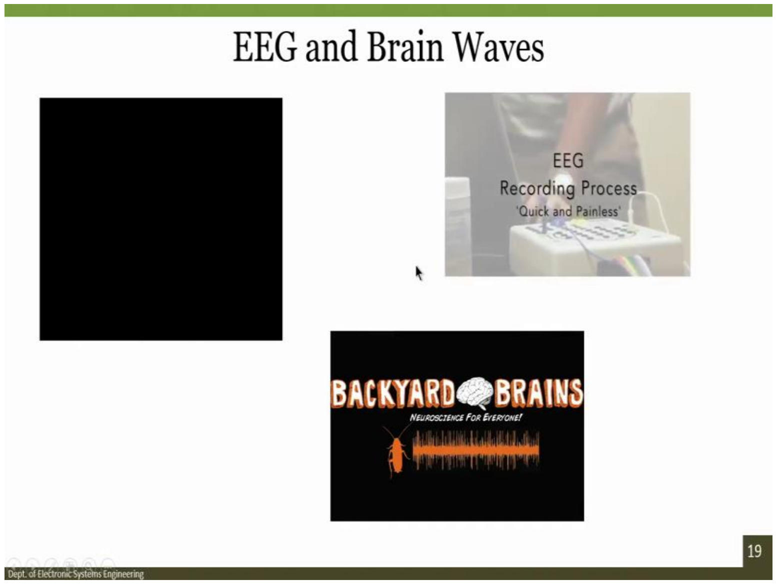

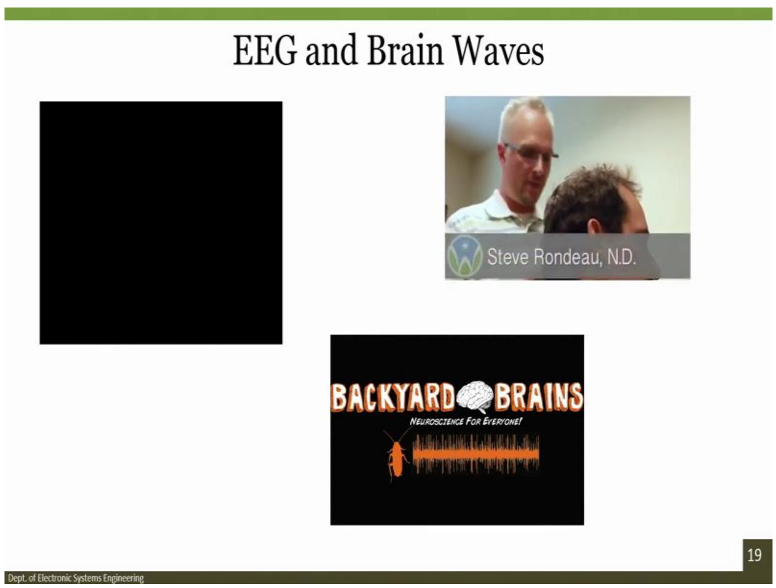

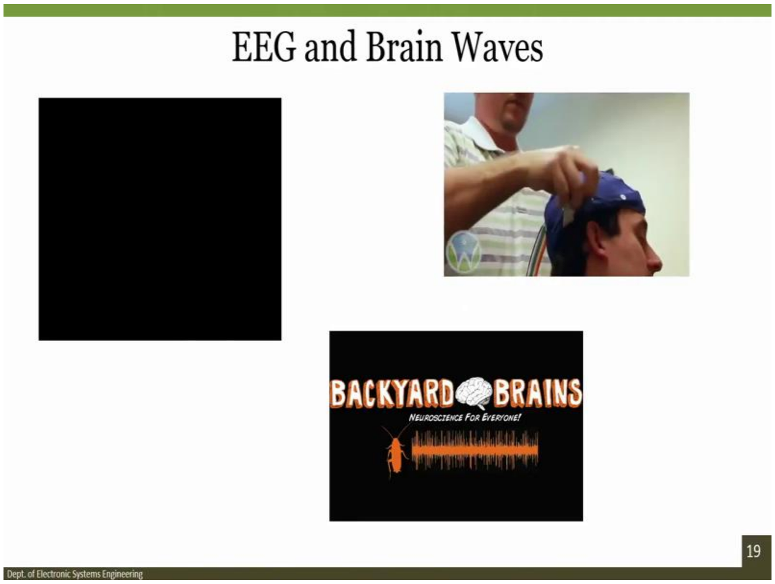

So we are going to be recording your EEG today. And so, essentially, what we are going to do is put this one cap over the top of your head. It does not have any feeling associated with it or any of the numbers. It is just a pretty easy process. But this little foam, these foam sponges on these here. Now the cap will go over here.

And so, the hardest part of the whole process is right here. This cap goes right over the top of your head just above your eyes. So just like that, we get two ear sensors here when I side. Okay. And the other side over here. So the hard part is over.

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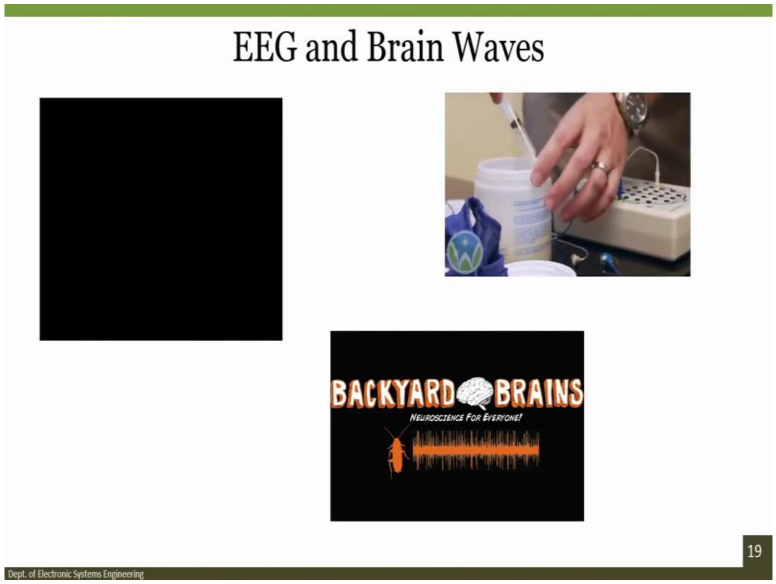

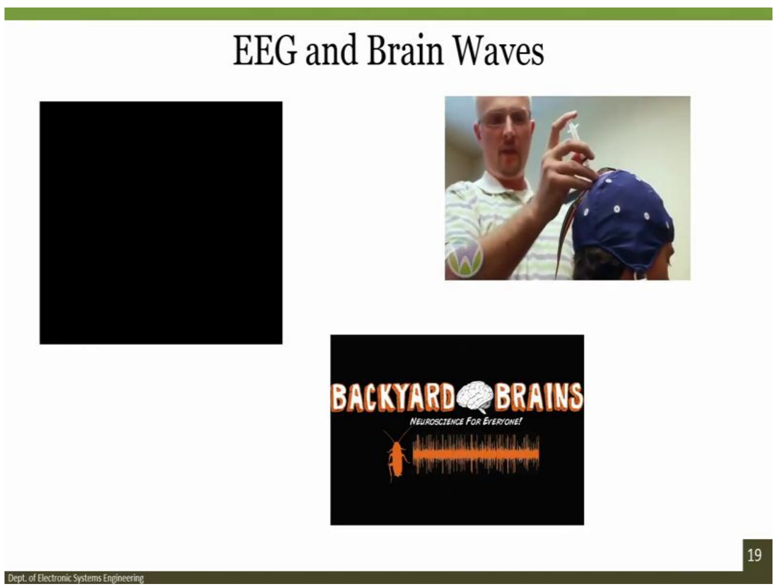

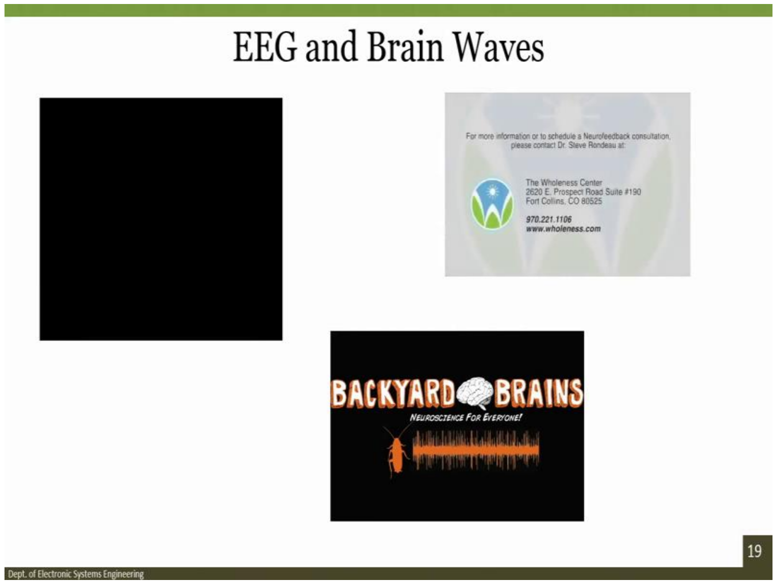

So now from here, all we do is I have this syringe, it looks like a needle, but it is not a needle just so you can see it is not sharp or anything here. And so, what I do is I take this, and I put the paste into each of these sensors, some here, some there, and in each of these holes, so that we can get a good connection between the sensors, and your scalp. So there should not be any pain involved or anything like that. It is just a connection between your sensors and your skull. So that is all there is to it.

And so what you will do now is just sit here for 10 minutes with your eyes closed, you look forward, sit nice and still, relax your shoulders, your jaw, your forehead, all of that and I am going to be behind you here recording the EEG. We, Will, do that for 10 minutes with your eyes closed and we will do 10 minutes with your eyes open, and then we are done. And that is all there is to it.

Professor: So you have seen 3 videos of the EEG, and from there what you see is that how EEG signals, how the electrodes are placed, what are the EEG signals, what are the ways to acquire these EEG recordings. But let us also see what are the applications of each and we will finish a module at that point. And then we will continue about the electronic conditioning circuit and in a later module.

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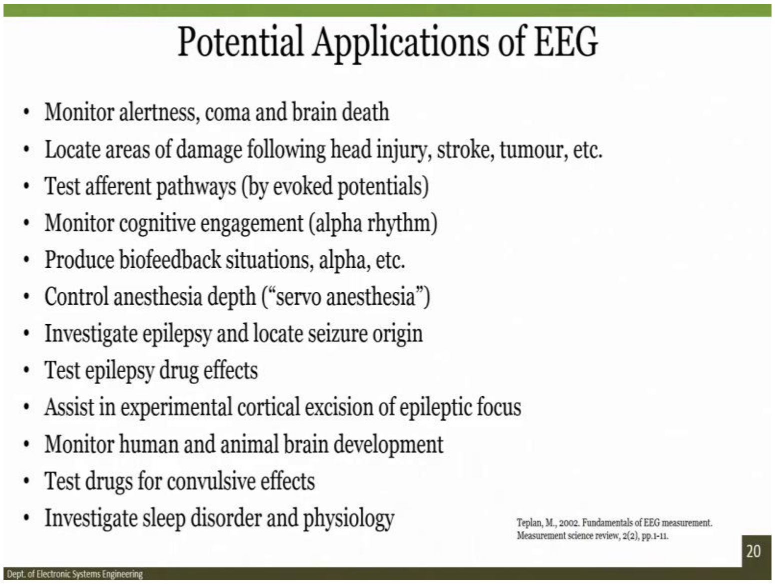

So this is the last slide of my this module and this is on the potential applications of EEG signal. So what are the potential applications of the EEG signal? The first application is to understand monitor alertness, coma, and brain death. Because from the brain waves, we can understand whether the brain is dead or the person is in a coma or there is alertness is there or not.

Second is, we can understand areas of damage following a head injury, stroke, or tumor. We can also test efferent pathways by evoked potentials, monitor cognitive engagement alpha rhythm, produce biofeedback stimulations, control anesthesia depth, which is control by servo anesthesia, in or in another term it is called servo anesthesia.

Investigate epilepsy and local seizure, we will discuss it in detail. Test epilepsy drug effects, whether a drug is having a high efficacy or not we can understand by measuring the EEG signals or ECoG signals in some time or for some applications.

Assist in experimental cortical excisions and epileptic focus, monitor human and animal brain development, test drugs for con convulsive effects, and finally, investigate sleep disorder and physiology.

So there are many applications of EEG because finally, EEG is related to nothing but your brain waves and brain waves show a lot of interesting applications, right from the deep sleep to a person whether he is in a coma not, to a person whether is attentive or not.

Let me give an example. If you can make a band to understand whether the person is attentive or not, then you will know the productivity of an employee. Suppose I wear a band, I work for 12 hours, how productive how effective I am, while I am working? Because your brain waves will show that okay, attention is decreasing and you can take a break in between.

Once you take a break when you come back, again, the signals will be different. That means you can measure the attentiveness of a person and you can improve the quality of the time invested by an employee in an organization. I am just giving an example.

Same thing you can also use for truck drivers. If they were the band, and as soon as you see that they are sleepy or they are less attentive, you can alert them on the dashboard saying that take a break. There is another example. So, so if you understand the brainwaves, if you understand EEG in detail you can use for thousands of applications in the area of research.

And that was the idea of this introductory, you understand the name of the course introductory neuroscience and neuro-instrumentation. We can, we can take an example and go in-depth of each of those may be in the next course, where it will be an advanced level of neuroscience and neuro-instrumentation. However, we will cover a lot of instrumentation techniques in this course.

And like I said, we will be discussing the cleanroom environment, we will be showing you some experiments within the cleanroom of how to operate the equipment, we will also show you how to use the EEG electrodes and how to acquire signals and, of course, a lot of things on neuroscience.

So, I will conclude this class here and I will see the next module talking more about the electronic modules for EEG acquisition. Till then you take care. I will see you in the next class. Bye.