Cognition and its Computation
Prof. Rajlakshmi Guha
Prof. Sharba Bandyopadhyay
Biotechnology and Bioengineering
Indian Institute of Technology, Kharagpur

Lecture - 08

EEG, fMRI, MEG

Welcome ah to our lectures ah on measurements. And so, you have learnt about how neuropsychological measurements can be done or make conclusions ah about ah cognitive processing based on ah neuropsychological measurements and also through eye tracking ah in humans . So, ah now we will go over a few more methodologies that are used in ah measuring activity of the brain based on which we can make conclusions about different aspects of stimulus processing or attentional states and also these are methodologies that are used by clinicians for diagnosing different illnesses. So, the primary ah among them that has been used for a long time ah is the electroencephalography method or in short it is called the EEG. This is ah completely non-invasive technique ah in the sense that ah other than ah little bit of abrasion on the ah scalp there is no other form of ah of ah tissue invasion in in the form of ah making cuts to get into closer to the brain or any such thing. ah is not involved at all in these procedures of EEG.

However, there is an intracranial EEG in which it is slightly invasive where the electrodes measuring the electrical activity of the brain are actually placed in under the inside the cranial region and so is more invasive and usually that is done in subjects who have who have a requirement of placing such electrodes. So, the non-invasive measure of EEG ah which is ah measuring the electrical activity in the brain it reflects ah overall summed electrical activity. So, the way the measurements are done is basically if you if I consider this the scalp and you will have pictures of the ah head and how they are placed. So, based on disk electrodes at various locations ah ah the the signal is collected ah from each of these points and with one reference the voltage across based on basically a voltmeter maybe with a small amplification is.

collected and ah provides a measure of the electrical activity in the cortical primarily the cortical region underneath the electrode. And depending on what the reference electrode is chosen and whether it is active in the process. ah that is it is ah it is contributing a large amount of signal during a particular ah data collection moment, the the results can be can become very varied. reference electrode in that sense has to be chosen carefully and has to be ah decided based on the particular question that is being asked and should be considered at a location that is probably not involved in the question that is being asked. So, as you have ah been ah told that it is the electrical activity of the neurons in ah the brain that reflect all the cognitive processing information processing attention ah decision making emotional processing ah aspects of reward all these things are ultimately based on the electrical activity of neurons.

So, ah we know that neurons are extremely small in size ah they they have a size of the order of 10 to 20 microns. And so, a volume of tissue let us say a millimeter by millimeter by a millimeter will contain a numerous number of neurons. It is not that they are tightly packed with only neurons, there are other other types of cells also in there . And so, Ultimately, it is the overall summed activity of of a volume of brain tissue ah a large volume in the order of few millimeters to even a centimeter that is collected from each electrode ah in the case of EEG. So, the electrode placements ah have a particular ah order or rather particular location based on the anatomy of the brain and they reflect different aspects ah in the processing ah by the brain and reflect primarily certain structures that are involved.

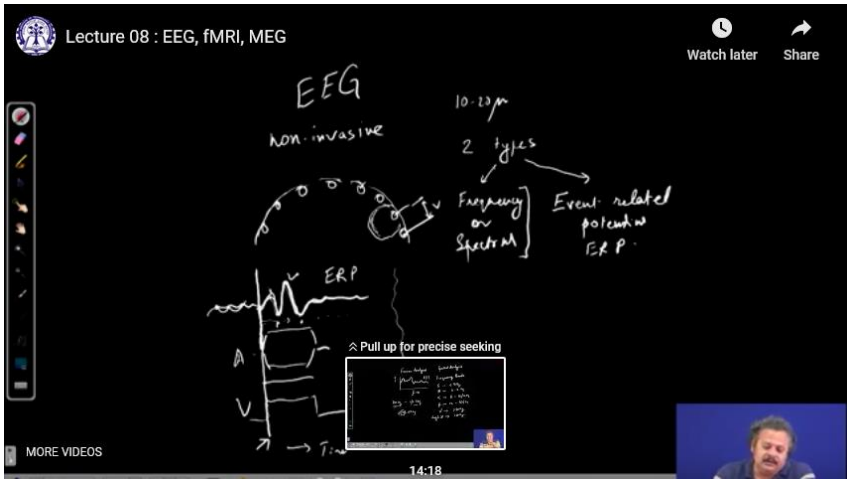
It is not very easy to conclude that the signal from a particular electrode is from a particular structure, it is not a straightforward procedure ah. However, course the spatial resolution ah is ah is not does not stop us from using the EEG for a variety of applications. primarily in a clinical setting and is used to diagnose ah many different ah disease conditions. And of course, as we will see in the course that EEGs are very useful for making measurements about how different regions or different frequency ranges of processing in the brain rhythms or the electrical signals are involved in different

cognitive aspects. So, as we go on, if we consider the electroencephalographic signal, we usually consider two types of ways to analyze it.

One is simply based on the frequency or spectral ah the frequency or spectral content of the signal and another is in the time domain ah which is usually ah triggered by an event which is called the event related potential or ERPs. So, the EEG signal that is reflected that is let us say ah that is collected ah with reference to a particular event in time, let us say ah reference to the onset of a stimulus, let us say we want to understand some certain things about multi sensory processing. and or maybe understanding how multisensory objects are integrated and let us say this is the duration of the ah stimulus and auditory stimulus and the visual stimulus that is associated with it that is ah played together and EEG is collected. So, this particular time so, this axis is time this is the auditory stimulus this is the visual stimulus. and the EEG signal is here ah for one electrode let us say.

And if we do repetitions of this ah ah color this experiment where we are playing this stimuli multiple number of times at different time intervals. Then, by averaging ah the EEG signals on ah one of the electrodes across those different times, we may get some sort of ah potential ah change over locked to the stimulus event which is this particular time point. This is what we will refer to as ERP or event related potential. And, they are the as you see I have purposely drawn an oscillatory kind of wave and these peaks and troughs which is the positive peak or negative peak, the first positive peak, the second positive peak, the first negative peak, the second negative peak and so on. or at a peak at a particular time with reference to the stimulus onset, these kind of features are used in different aspects of the analysis when we deal with event related potentials.

(Refer Slide Time: 10:39)



So, this is one way of looking at the EEG data or the overall electrical activity ah that is being collected from the scalp ah based on probably activity of many many neurons ah thousands of neurons or even tens of thousands of neurons ah simultaneously. So, these the other way in which we also look at EEG data is basically in the spectral domain as we said or in terms of the frequency content. So, as you may be familiar with the idea of Fourier analysis or ah the spectral analysis that is that is we we obtain the energy or power at ah at different frequency ranges. So, if we have a particular signal ah we can obtain as a function of frequency The amount of power or energy that is present in the signal as a function of frequency. So, let us say this is power and this is the frequency axis and the spectrum represents the spectrum represents this is p as a function of frequency the amount of power in a particular frequency.

So, we collect EEG signals generally with a sampling rate of about 250 Hertz. up to 2 to 4 kilo Hertz ah this is already too high. I mean the major content of the information in terms of spectral information in AG signals is present ah within ah 100 to 150 Hertz ah. I mean usually the biggest component is less than 100 Hertz. And so, ah 250 hertz sampling although temporarily coarse is sufficient for many purposes.

If you want to get information in spectral content above ah 100 hertz, then we go for ah higher sampling rates. or above rather 50 hertz we go for higher sampling rates. So, the key features in this spectrum is based on ah some understanding of ah the frequency

analysis and that is ah we divide the spectrum into different frequency bands. these frequency bands have a particular name and they are over a particular range. So, the first is the delta band which corresponds to about less than 4 Hertz.

Then there is the theta band which is about 4 to 8 Hertz. ah then it is the alpha band which is 8 to ah 12 or 13 Hertz ah. beta band which is ah around 12 to about 30 Hertz and greater than that is the gamma band which is greater than 30 Hertz. And sometimes our people also consider a high gamma and that is ah around greater than 50, 60 Hertz. So, the reason for dividing the EEG spectrum into these bands is that gradually throughout the course you will see that these particular ranges of frequencies like delta, theta, alpha, ah tend to represent certain aspects of ah stimulus processing or certain cognitive states or ah the involvement of certain regions of the brain and so on.

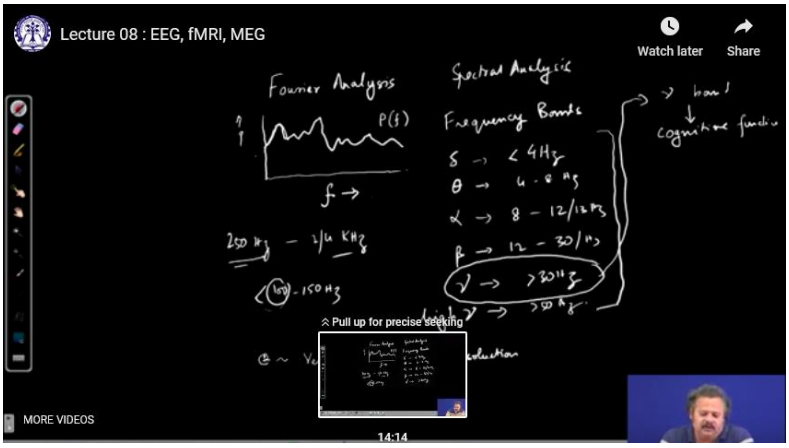
all these a very very important ah band that will be into play ah in our later lectures when we talk of more about perception attention and other aspects of cognition is the gamma frequency band. ah It is generally tied to a lot of ah cognitive function. ah Similarly, ah the beta band alpha band ah all these have their ah significances and we will be going over different ah of aspects of these ah when we touch upon them. So, essentially when we get the collect the EEG signal from ah the different electrodes we have to filter out the signal in each of these different frequency bands by the use of appropriate filtering ah techniques ah which we will not go into these are now standard procedures that are available to ah filter out how much energy or power is there in each of these frequency bands. So, this is ah a way of measuring brain activity and then ah correlating ah these with different events or different ah ah contexts in which this EEG is being collected.

And, then concluding ah make making correlational observations about changes in some of these frequency bands and some particular phenomena that is ah being studied. So, ah the main ah important advantage of EEG is that it is extremely ah simple in the sense of ah being able to perform the experiment. Ah They are readily and cheaply available in if they are ah not too many channels that are involved. And, in a simple clinical setting we can gain access to EEG signals of a patient and make conclusions. Although they have

very poor or coarse spatial resolution that is signals from an electrode cannot be localized to specific structures in the brain.

we can still use the information to make conclusions about disease states and cognitive processing. Similarly, the another advantage is that since we can sample at 2 kilohertz, these have very good spatial resolution, very good, I am sorry, very good temporal resolution. Now, what we will see later on in another methodology that is often used which is the fMRI or functional magnetic resonance imaging, where the temporal resolution is extremely poor in the sense that it is in the scales of hundreds of milliseconds to seconds. Whereas, here the temporal resolution is in milliseconds and that often allows us to identify specific features in event related potentials and how that changes based on state of the person and so on. Another ah very very important thing is that ah if we compare it with other ah methodologies like fMRI or MEG, this is ah orders of magnitude cheaper in terms of ah how ah how much it costs or and how easily it can be implemented.

(Refer Slide Time: 19:30)



So, with these advantages and disadvantages of EEG, there can be, there are many more, but these are the most important things to remember. We will go into the other methodology that we will talk about and is used primarily in a research setting and less in

a clinical setting which is functional magnetic resonance imaging. So, that is functional magnetic resonance imaging. So, an MRI which you have heard about which is magnetic resonance imaging only ah this is more of a structural imaging. And this allows us to ah identify ah specific structures in the brain or even in the other parts of the body in ah depending on what ah we want to image ah.

Now, that we are talking about the brain the MRI can be used. ah to identify changes in thickness precise changes in thickness of the cortex let us say or if there is atrophy or not ah in a particular region of the brain or and so on. And ah functional magnetic resonance imaging is ah using the magnetic resonance imaging technique. But, it provides the additional information of how activity or neuronal activity in the ah changes with time and we can have just like EEG, we can have this functional MRI information ah or activity related information from variety of different regions in the brain. The principles behind how we measure fMRI signals is essentially based on usage of glucose in the brain ah by ah neurons or brain tissue ah for active neurons.

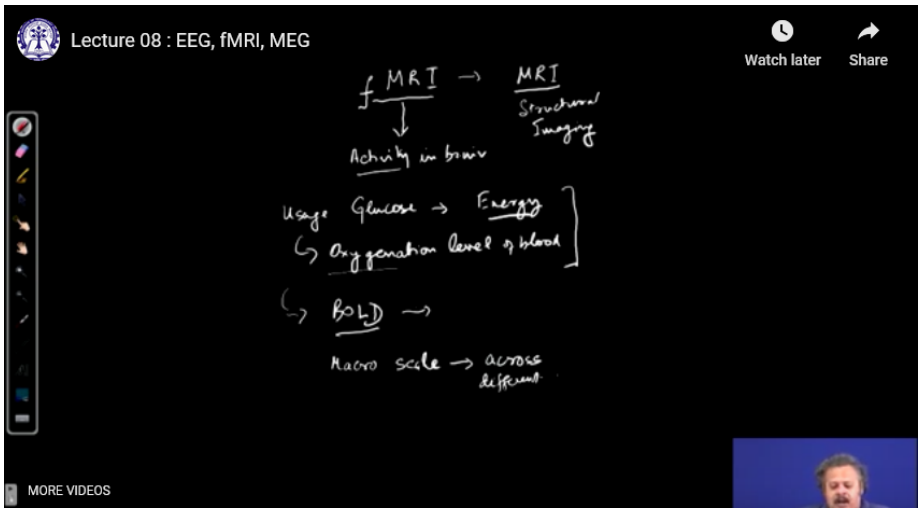
So, ah when ah neurons are very active for this activity to they ah require pumping of ions as we will see in later lectures where we discuss what this specific activity is and how it is maintained. So, we require ah energy in that specific region of the brain ah and energy is provided by glucose that is supplied ah by the blood. And so, depending on the usage of glucose the oxygenation level of the blood changes. So, the oxygenation level of the blood changes meaning ah either it I mean the it is the oxygenated hemoglobin or deoxygenated and based on that the properties of that local region of the brain ah the magnetic properties ah change. The ah the different levels of magnetization ah produced by the oxygenated and deoxygenated blood is probed with an RF pulse which changes the level of magnetization ah in of the nuclei.

And ah once the RF pulse is removed ah the magnetization level falls back and it emits the fMRI signal which is picked up by coils. This signal ah by RF coils and ah that is what produces the actual fMRI signal. So, that signal is then pre emphasized with a filter and then amplified and so on. So, ultimately it is the difference in the deoxygenated and

oxygenated bloods magnetic properties that govern the principle behind the fMRI signal. And, depending on how much activity is there in a particular region of the brain that determines basically the amount of oxygenated blood in that in that particular region and the relative levels of deoxygenated blood in that region.

And ah this ah differential effect ah that is what is ah used to measure the level of activity at that particular location or region of the brain. And in fact, simultaneously ah many different regions are ah imaged. It has a very poor temporal resolution because the peak of the signal reaches around after 2 to 4 seconds after a stimulus or task or whatever is the trigger for the change in activity of the signal. And the changes this differential change then allows us to know how much activity or blood oxygenation level dependent measure of activity which is the bold signal that indirectly gives us which region of the brain is active and so on. So, the important advantage here is that we can collect signals from many different ah positions simultaneously or near simultaneously ah within a slice of ah brain tissue and ah So, unlike the EEG method we can actually identify specific locations and how much activity is going on in there simultaneously between two ah different structures and at a macro scale ah a very important amount of ah very important information can be provided at a macro scale across different regions ah of the brain.

(Refer Slide Time: 27:40)



Although the spatial resolution is ah still poor within that ah region, we do get access to many different slices and depending on how we direct the magnetic field ah to the particular structure that we might be interested, we can gain in spatial ah we can play with spatial and temporal resolution and get ah required information. However, since it is based on the oxygenation level of the blood and over a large region of the tissue, this indirect method of getting at the electrical activity in the brain or in the neurons of the tissue, very specific conclusions about ah processing by neurons is not ah ah fully possible. Although ah many aspects of ah ah cognitive processing with fMRI can be addressed many questions can be asked and as we will see in the course ah based on fMRI there are ah many aspects of ah cognitive processing that we will ah be talking about later on. So, with these discussions on ah overall ah core spatial level ah activity measurements from the brain, ah we will stop ah this lecture ah at this point. And, in the later lectures we will talk about methodologies or measurements ah that can be done at more finer ah spatial and temporal resolutions going to the level of almost single neurons and then exactly single neurons ah to gain further and richer information ah we will look ah at how we can get information from particular types of neurons even.

those will be coming up in ah later lectures. Thank you.