Introduction to Brain & Behavior
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Lecture-08
Studying the Damaged Brain

Hello, and welcome to the course Introduction to Brain and Behavior. I am Dr. Ark Verma from IIT Kanpur. This is the second week of the course and today we are going to talk about Studying the Damaged Brain.

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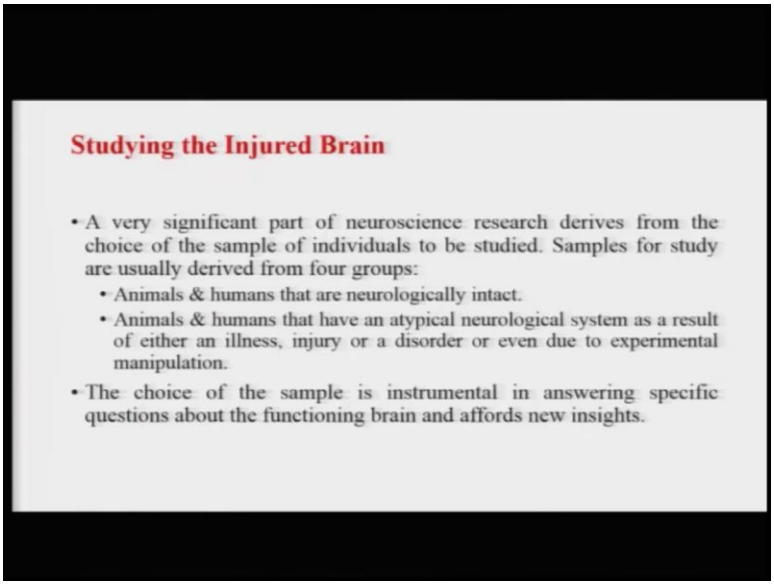

Now, studying the injured or the damaged brain has very significant advantages and that is one of the reasons why it has been a very significant part of neuroscience and neurology research over a longest period of time. One of the things basically that drives most of the scientific research or scientific research especially in behavioral sciences is basically being able to select the, collect sample of population to work on or to investigate let us say the neurological functioning or something.

There are typically four kinds of groups that are used for studies not only across behavioral sciences, but mainly in neuroscience research. These are neurologically intact animals and humans and neurologically impaired animals and humans. And this impairment to the neurological system or the atypically functioning neurological systems can be arising as a result of various causes. It could be due to an illness and injury or a disorder or sometimes even due to genetic malfunctions or genetic defects etc.

These samples or these, the choice of sample from each of these four groups is basically made or it is basically done to suit the researches, questions and to be to allow them to test a very specific hypothesis about neural functioning. So this is something which is a very very important portion of very very important question in neuroscience research, basically saying that the sample that you choose to work on will basically decide the extent of the answers that you are going to get.

I will give you an example. Suppose I want to understand, how does, what is the role of let us say left inferior frontal area of the brain, what is the role of that area in a particular mental function. Say language production or a comprehension. What other things I could do is I could actually take people who have lesion in the left inferior frontal lesion of the human brain and then ask them to perform certain tasks, maybe ask them to name something, ask them to describe something using language or I recite to them some passages and see whether they have completely understood that or not.

That is one of the things I could do, or I could basically do this with neurologically intact individuals but have some methods of measuring their brain functioning or measuring the functioning of this specific area which is the left inferior frontal area of the brain. Both different kinds of samples will basically tell me different things or will have the potential to tell me something unique role of this particular area of the brain.

If I am looking at the neurologically intact individual and if I have a way of measuring the functioning when the participant is performing this task or while they are producing speech or comprehending speech. On the basis of the measurement, and I will be able to know the degree of involvement of this area in either of production of language or comprehension of language. That is one way that I can determine or check whether this particular area is involved in producing or comprehending language or not.

On the other hand, if I am talking about neurologically impaired individuals or individuals who have specific lesion in these sites, I will sort of get a picture of whether the individual is not able to perform the task, what is the nature of the deficit, what is the exact deficiency or impairment that the person is facing with respect to this specific task, so that I can infer that okay, this particular aspect of let us say language production or comprehension is impaired when a person has damage to this particular area of the brain. So this is basically one of the reasons why choosing the correct sample to study is a very important question in neuroscience research.

Let us move on. Let us look at varieties or causes of different kinds of atypical neurological function. One of the first causes is vascular disorders. Now, vascular disorders basically arise when say for example, there is some kind of a tissue damage in the brain because of partial or complete loss of supply of oxygen or glucose to the neurons in the brain.

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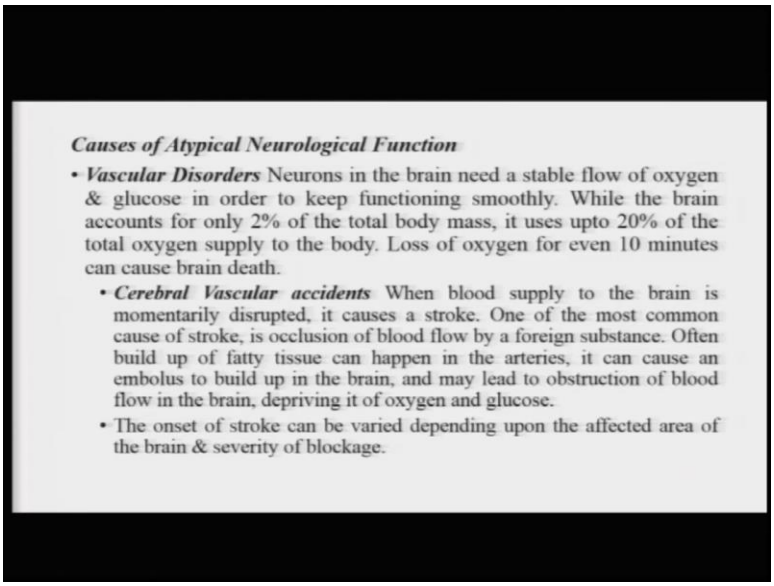

Now, neurons in the brain need this, they need a stable flow of oxygen and glucose in order to keep functioning smoothly. The human brain is, so neurons in the brain need a steady flow of oxygen and glucose in order to keep functioning smoothly. The human brain basically is an energy intensive organ of the brain, because it accounts for almost 20 percent of the total oxygen intake of the body even though it accounts for only 2 percent of the body's mass.

Cerebral vascular accidents can happen when the blood supply to the brain is momentarily disrupted, and it leads to causing a stroke, but the most common causes of stroke is the occlusion of blood flow in the brain by a foreign substance. This foreign substance could just be say for example, some kind of a fatty tissue that has built up over time in the arteries and suddenly becomes large enough to obstruct the flow of blood.

As soon as the fatty tissue becomes large enough to obstruct the flow of blood in the brain, it can cause stroke, or if it continues, if the obstruction goes on for a longer time, it can cause immediate death. The onset of stroke basically can depend upon a variety of factors, but it majorly depends upon the area of the brain that is affected, the area of the brain where the blood flow is being obstructed and the severity of blockage.

Is it a partially blockage or is it a complete blockage. So these are some other factors that govern the extent of injury that can happen to the brain in case of vascular disorders. Another example that can cause damage or injury to the brain is the growth or the development of tumors.

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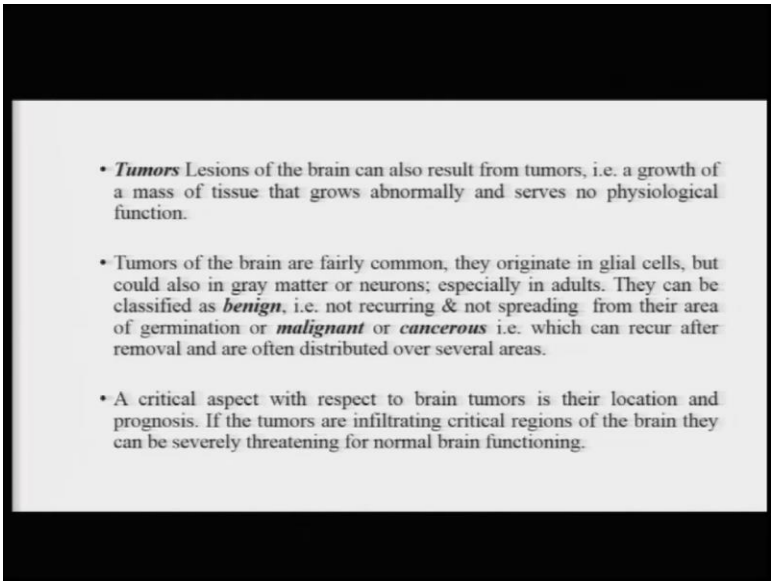

Now tumor basically is just a mass of tissue that grows abnormally and has no physiological function whatsoever. But tumors in the brain are fairly common, they mainly originate in the glial cells and sometimes could also originate in the grey matter on neurons, especially in the case of adults.

Now, tumors can be of two type, they can be either a benign tumor which on which does not really spread out, it is not recurring. Once it is removed, it does not usually come back, or a brain tumor could be malignant or cancerous, which can come back once it is even surgically removed and typically it spreads over the area of the brain and it increases in size, and it increases in its spread in the brain.

Now, basically, what the tumors could do is that they could actually the way they progress, the way they increase, they can obviously cause, infiltrate critical regions of the brain and they can severely disrupt the functioning of the brain. And in essence, the presence of tumors is also very very important, a very dangerous condition for somebody's brain to have.

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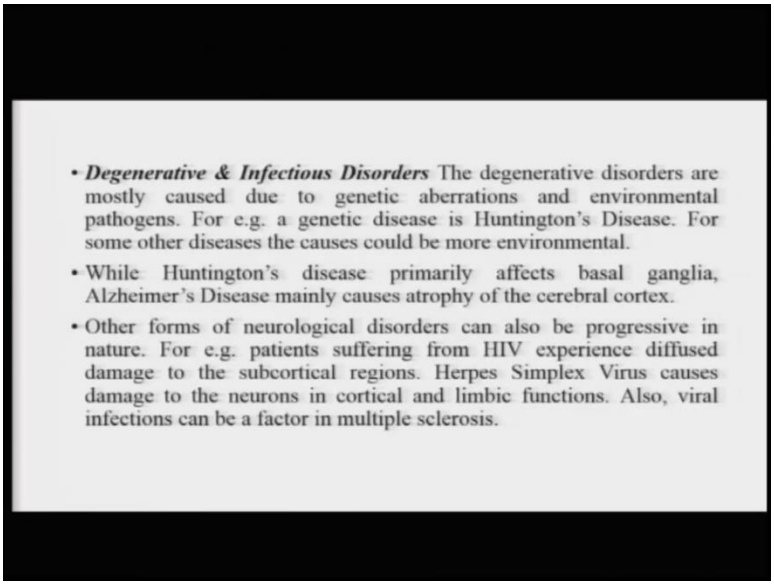

We can talk a little bit about some kind of degenerative and infectious disorders which can also lead to problems with the normal brain functioning. Now degenerative disorders generally are caused due to genetic aberrations and sometimes due to environmental pathogens. So for example, Huntington's disease is an example where the cause of the disorder or the cause of the atrophy in the brain is mostly genetic, whereas there are other disorders where say, for example, Alzheimer's or Parkinson's disease where the cause of the disorder could actually be environmental as well.

There are other forms of neurological disorders as well which can be progressive in nature and can damage the brain in increasingly severe manner.

Say for example, patients who suffer from AIDS or the human immunodeficiency virus sometimes causes diffuse damage to the subcortical regions of the brain and similarly hurt people who are suffering with the Herpes Simplex Virus. They also experienced damage to the cortical and the limbic functions of the brain. Sometimes even viral infections can be one of the factors in multiple sclerosis developing. So there are some of these infectious disorders, some of these degenerative disorders like Huntington's and Alzheimer's which can cause or disrupt normal brain functioning to a great extent.

Another factor that could cause atypical brain functioning or could cause a severe injury to the brain is a traumatic brain injury.

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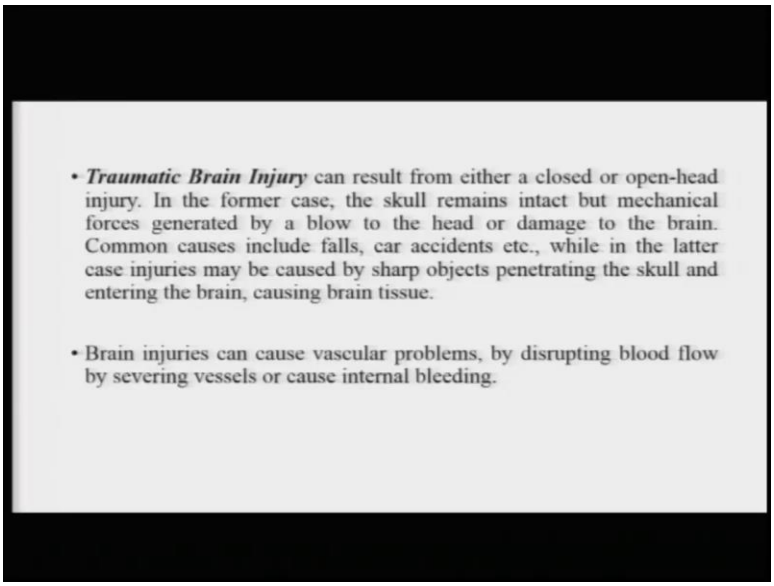

A traumatic brain injury can be either closed or open head injury, while in the former case, in case of a closed head injury, suppose you have banged your head or you have fallen and you have hit your head with a bit of a momentum, with a very hard object, it will basically cause damage to the brain, it will typically does not involve penetrating the skull but, it can cause internal bleeding, internal damage to the brain tissue.

Similarly say, for example, open head injuries are where basically something enters the skull it fractures the skull enters it and damages the neural tissue by entering the area of the brain. So both kind of injuries are fairly dangerous and can cause irreversible damage to the human brain.

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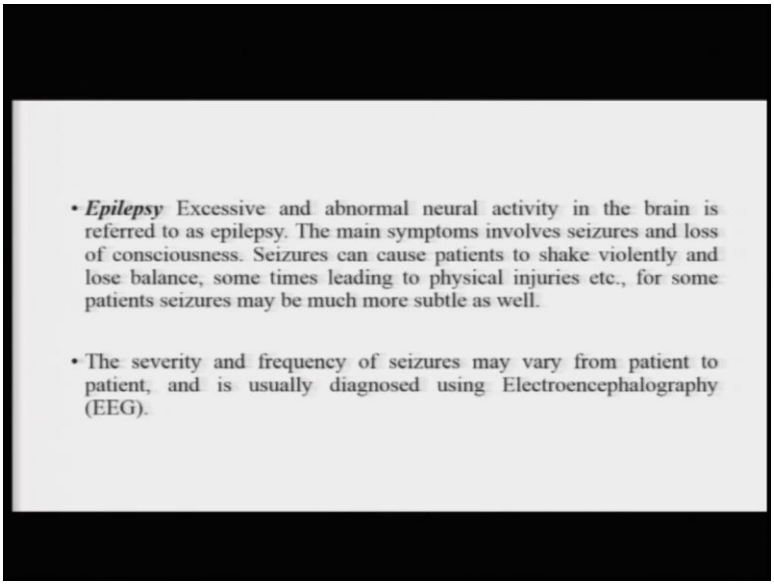

Another factor that has been traditionally seen to disrupt the functioning of the human brain is epilepsy. Epilepsy is nothing, epilepsy is basically excessive and abnormal neural activity in the brain and it basically leads to the patient experiencing seizures and temporary loss of consciousness.

Seizures can cause patients to shake violently, you might have seen people around you or say, for example, sometimes in the television, etc, that when the seizures are onset, typically the patients would shake rather violently, they would lose balance, they would fall sometimes leading to physical injuries, etc.

And that is one of the ways for some cases, for some patients, the seizures might be quite subtle as well so that nobody actually notices it and the person still experiences a seizure. Now, the severity and the frequency of seizures in epilepsy may vary from patient to patient and is usually diagnosed using electroencephalography or EEG.

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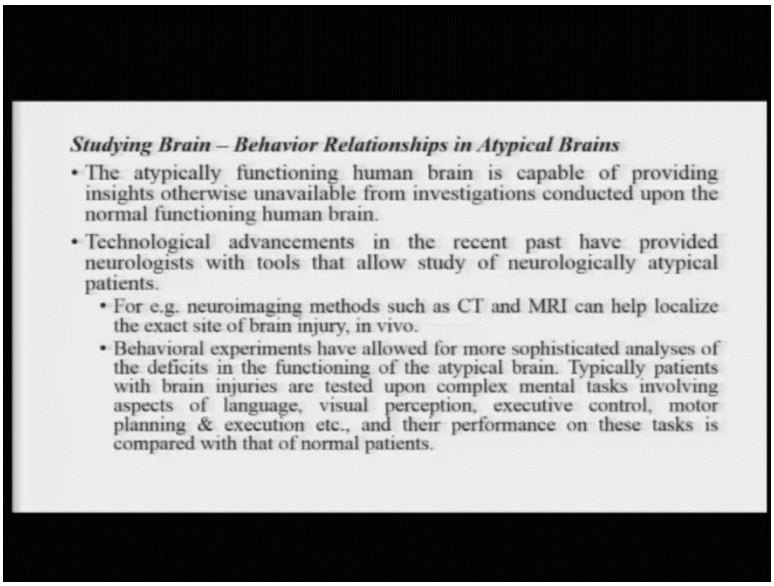

Now, these were some of the disorders or some of the possible ways in which normal brain functioning could be disrupted or the normal human brain can be damaged. Now, as I was saying that studying various aspects of the functioning of this atypical human brain is fairly necessary. So the atypically functioning human brain is actually capable of providing insights that are otherwise unavailable from investigations conducted upon the normal functioning brain or neurologically intact individuals.

It just so happened that in the recent years, there have been these technological advancements that have provided researchers or neurologists with tools to be able to assess the study of or to assess and study the functioning of neurologically atypical patients who have some kind of brain damage, we have seen so many causes. It has become important to study some of these patients.

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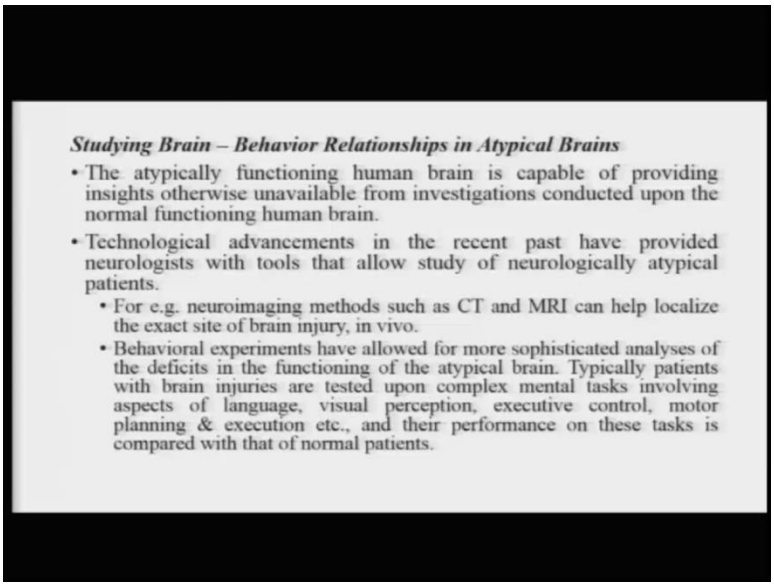

Now, say for example and let us take an example. Neural imaging methods like CAT scan or MRI can actually help localize the exact site of brain injury while you are examining the patient and the patient is alive and doing stuff, so, typically it can it can help one determine that okay, this is, these are the deficits of the cognitive functioning.

Suppose the person is not being able to speak fluidly, suppose a person is not being able to recognize objects, etc. MRI can, say for example, give you a static picture of which areas are exactly damaged in the brain. And later, what the researchers would do is they would try and correlate the degree of deficit with the exact area of the brain that has damaged.

Behavioral experiments that have been developed or over a range of years. Mike Posner and others and so many other in intuitive paradigms we keep coming across every other day, have also allowed for a more sophisticated analysis of the, analysis of the kind of deficits these patients experience because of any of these injuries or because of any of the causes that are causes that are leading to atrophies in the brain.

Typically, what researchers would do is that they would compare patients with brain injuries, they will take these patients with brain injuries in and ask them to perform these complex mental task, which involve various aspects, say sometimes language, sometimes counting, tearing away drawing something. So there are these batteries of neuropsychological tests or tasks that these

patients with brain injuries are asked to do and then their performance is compared with a controlled group of patients who do not have that injury.

And this comparison basically lets us know gives us insight into what exactly is happening in terms of performance or in terms of the actual deficit that is coming out of this particular injury or this particular pattern of atrophy. So this is something which is fairly important.

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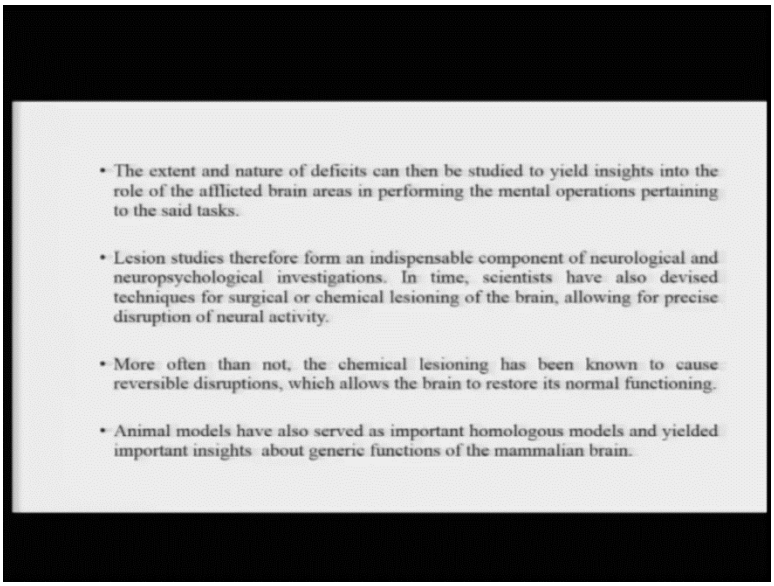

Now the extent and extended the nature of these deficits once these tasks have been administered can then be studied in more detail to yield insights into the role of the afflicted brain areas in performing the mental operations pertaining to the said tasks. Suppose you ask somebody to pretty calculation, just ask them to do 2 plus 2 is equals to 4, 2 into 2 is equals to 4 and those kind of things, basic mathematical arithmetic calculations.

And if a person is suffering from some lesion or some stroke, which has caused injury in the left hemisphere of the brain or say like right hemisphere of the brain, typically what you would do is you ask the person to do these tasks and see whether the person can do one version of this task, but not the other version of this task or the other version of this task, but can perfectly perform in a different task.

So you kind of compare the person's performance across task. And basically what you do is you analyses the task demands and on the basis of this analysis, you say, okay, these were the task demands that could not be met by this individual who has injury in area A of the brain. You then can correlate that area A might be involved in fulfilling this particular task demand. So this is a typical method that people use to sort of study individuals with sort, with different degrees of brain damage.

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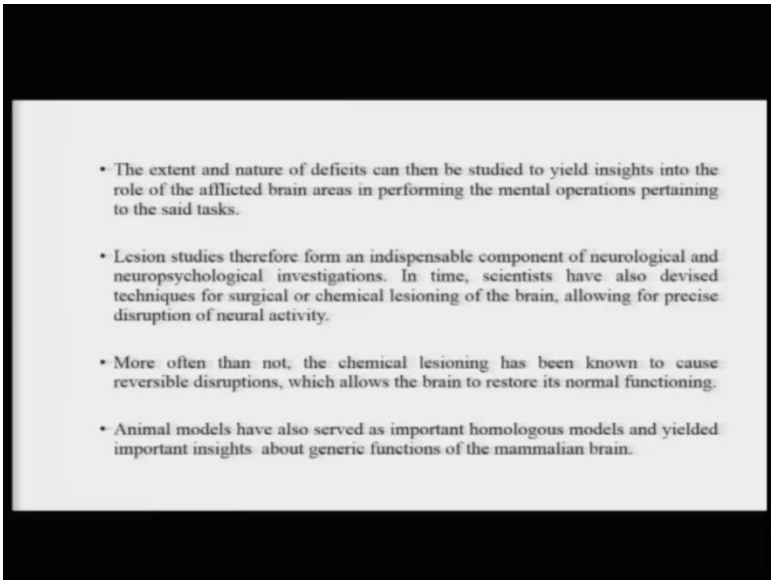

Now, lesion studies for reasons that I have just mentioned, form a very indispensable component of neurological and neuropsychological investigations. In time scientists, have also devised techniques for surgical or chemical lesioning of the brain, allowing for precise disruption of neural activity.

So people have researchers, neurologists neuropsychologists have actually developed devised methods of chemically inducing or surgically inducing lesions in particular areas of the brain so that they are able to sort of study the results or study the ramifications of injury to very specific sites in the brain.

Now, more often than not, this chemical lesioning is reversible, it causes reversible disruptions, which allows the brain to return to its normal functioning after the experiment or the study has been conducted.

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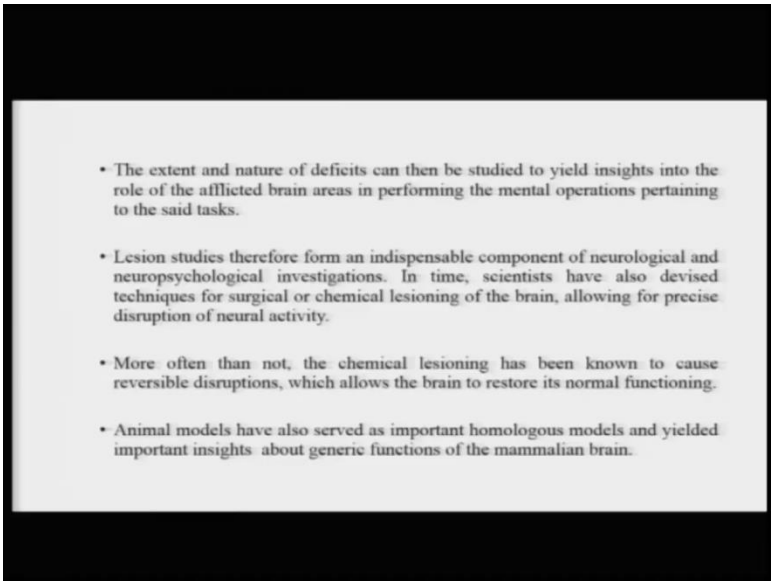

Similarly, animal models have also been extensively used as important homologous models for the generic mammalian brain and a lot of insights have been derived from these, from the mammalian brain with respect to how the human brain might be functioning. I can remember of an example of the discovery of mirror neurons, which was first discovered with macaque monkeys.

And later, the discovery, later it could also be shown that the mirror neurons are present in the human brain as well. But the presence of mirror neurons in the macaque monkeys was actually a very important step and it kind of led to a lot of theoretical revolution almost in fields of language evolution, in fields of motor studies, apraxia and so on.

So, a lot of these animal models, as I was saying, have been proved, have proved very useful for studying the functioning of the human brain. Now, although the lesion approach has its own advantages, it has some limitations as well. For example, naturally occurring lesions, what are naturally occurring lesions, if somebody gets injured, if somebody suffers from an viral infection and that causes, that infection goes up to the brain and causes some kind of neural damage,

basically these are very very difficult to control, the exact site and the exact severity of the lesion becomes almost impossible to control. So it becomes almost unmanageable as to sort of study what the kind of deficit is basically going to be experienced by the patient and how is this deficit to be directly mapped onto the damage of tissue in the in the brain.

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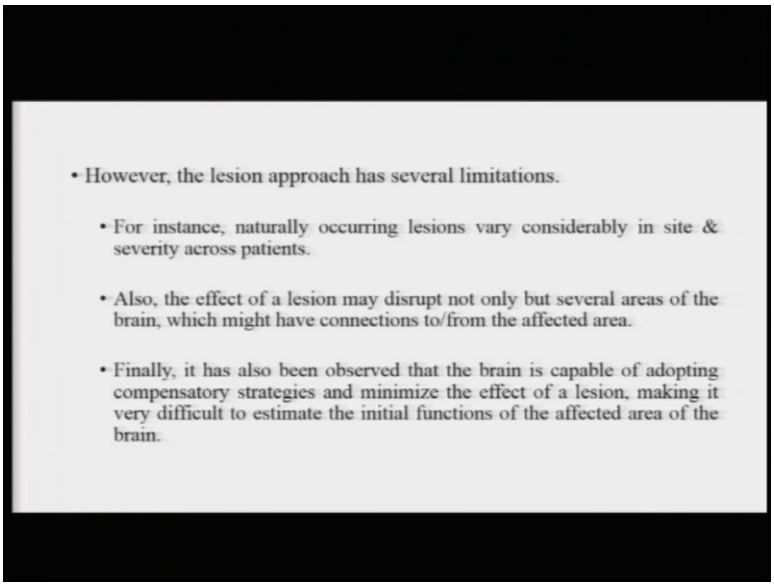

Also it has been observed, it has been documented that the effect of a particular lesion may disrupt not only the site at which the lesions happen, but several areas of the brain which might have connections to or from this particular area of the brain. If you remember, we have seen that brain is this structure of foldings of neurons all along and obviously, the brain a different region, all the regions of the brain are interconnected with each other.

So what could happen is that, okay, if this region of the brain is damaged or injured, this the functioning associated with this region will be damaged, all right, but this region was also an important center for providing input to the other region, which was dependent upon these regions.

So what will happen is, some functions will also be disrupted which are linked to this region, but you have no way to sort of get to that point in most of these lesion studies. So this is also one other very important thing.

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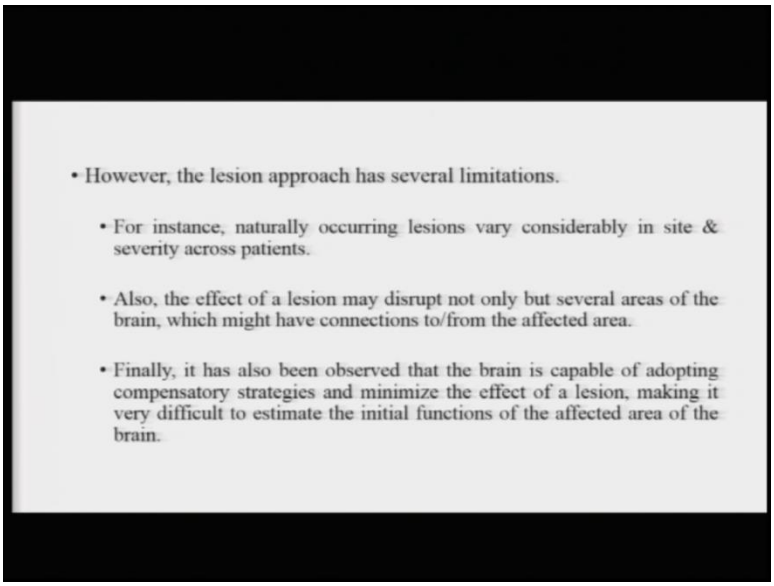

Also another factor that could act as a limitation for these lesion studies is the fact that the human brain is a very fascinating organ, it is basically capable of adopting compensated strategies and minimize the effect of lesion, making it very difficult to actually estimate the initial functions of the affected area.

Say for example, what happens is if there is area A and area B of the brain, area A was involved in doing function X and area B is involved in doing function Y, if the injury has happened at a much earlier age, and if the person has got time to heal nicely, what can happen in some patients, especially in younger patients, is that the brain will sort of adopt a compensatory strategy such that area B will also take a function X and will now be performing both function X and Y.

So typically what you will see is then it is very difficult to estimate that what exactly area A was involved in doing, because it might be possible that only a very small degree of deficit is observed. So all three of these reasons actually tell us that lesion studies, although they are very beneficial, will have some disadvantages as well and therefore the results and the analysis and the conclusions that come out of these lesion studies need to be really considered very carefully and understood in the context of the, of a specific patient.

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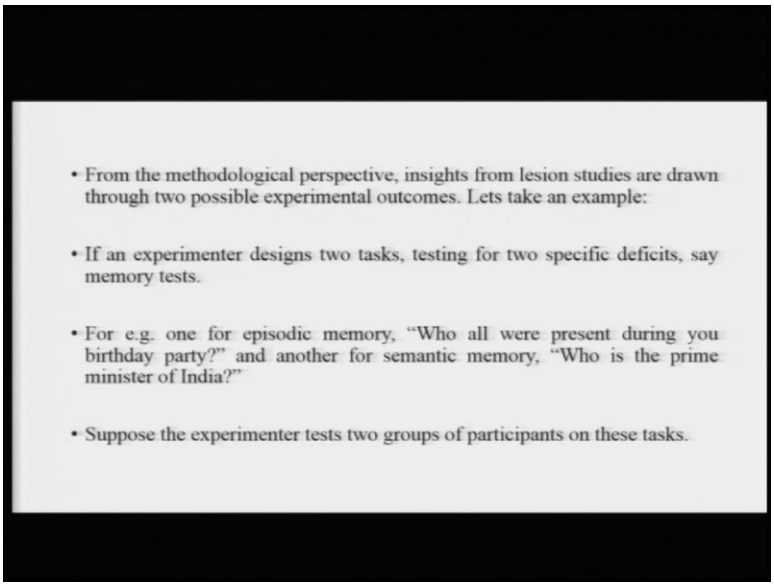

Now, from the methodological perspective, lesion studies are drawn, conclusions are drawn from lesion studies through two possible experimental outcomes. Let us take an example. If an experiment that has two tasks, let us say task 1 and task 2 and I have taken example here of memory.

Suppose there is an experiment to develop two tasks, two task is for testing episodic memory, you can ask somebody that, okay, who all were present during a birthday party? Where did you go for your vacation? Things like that. And another for semantic memory, where you, where you have to just ask the person about facts. Say for example, who is the Prime Minister of India, or what is the capital of, you know, Philippines, things like that.

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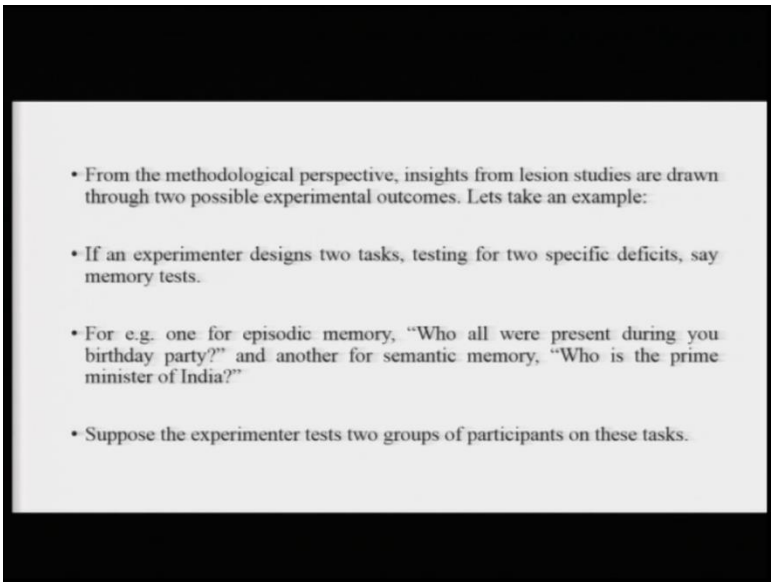

Now, suppose the experimenter is testing two groups of participants on these tasks, there are two things that can happen. One of the two groups of participants shows deficiency or only one of the two tasks and not on the other, the pattern of deficit will be referred to as single dissociation. It will basically be established that the area of the brain that is damaged was involved in doing this particular task, and hence the damage to this area is causing deficiency to just this task.

But there is a bit of a problem in interpreting the single dissociation pattern or findings from the single dissociation experiments is that it is quite possible that one of the two tasks was just more difficult. Suppose task A is all right, but task B is affected, but it is quite possible that the task B is just a more difficult version of task A. So what is happening is that this area is not really linked to task B, just that it is a little bit more difficult and that is why the area involved is not being able to accomplish that task. So that is also possible.

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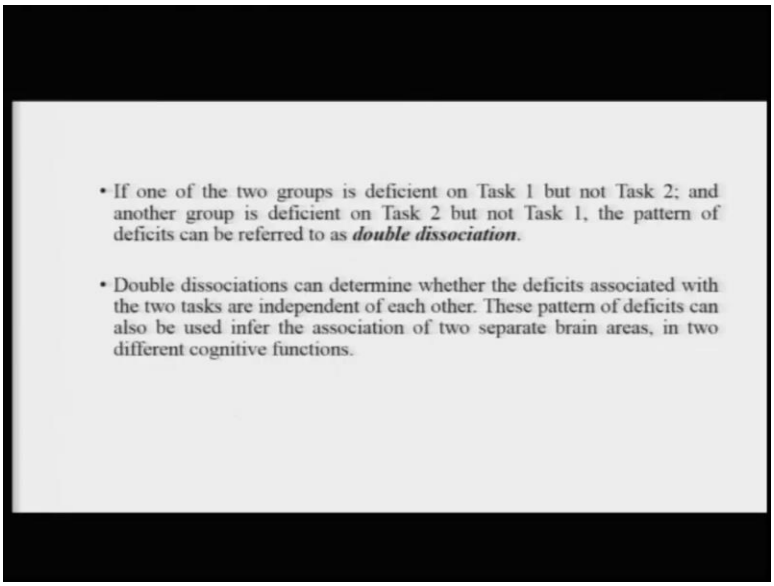

Now, if one of the two groups is deficient in task one, but not task 2, and another group is deficient on task 2, but not task one, the pattern of deficits can be referred to as double dissociation. Double dissociations can actually help be to mind whether the deficits associated with the two tasks are independent of each other or they are sort of linked with each other.

These patterns of deficits have been used to infer the association of two separate brain areas with two different cognitive functions. Say for example, a classic example could be of the broca's area and wernicke's area and say for example tasks which have to do with language production and language comprehension.

Patients have been discovered who had deficit in the broca's area so they could not produce speech, but comprehend speech perfectly well. There have been patients who have had lesions in the wernicke's area who could not comprehend speech, but could produce a speech relatively all right, okay?

So, these are some of the patterns and a lot of patient profiles sort of unravel some of these patterns where it can be observed that the two deficits are independent of each other and can then be linked with two separate areas of the brain.

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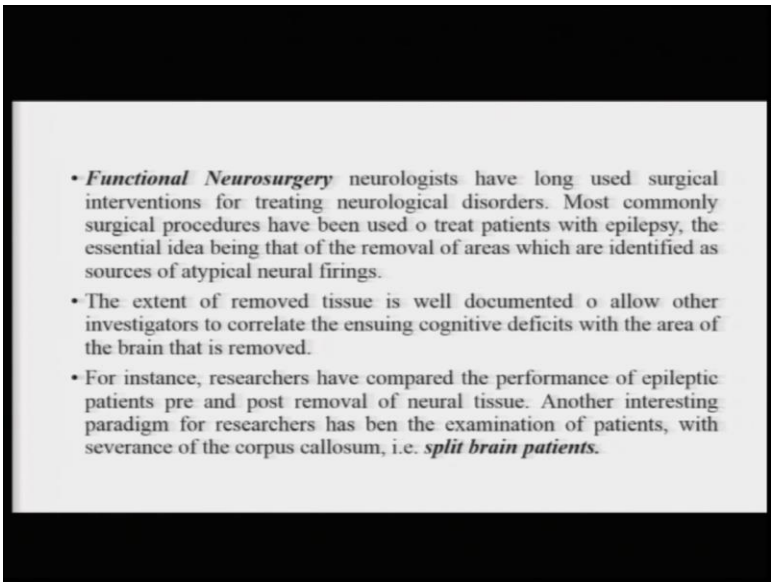

Functional neurosurgery is one of the ways in which you can actually look to disrupt the normal brain functioning. So neurologists have long used surgical interventions to treat neurological disorders. Most commonly surgical procedures have been used to treat patients with epilepsy in the manner that say, for example, the essential idea is that neurologists were looking to remove the areas of the brain which were the source of atypical abnormal neural firings.

The extent of the remove tissue did very well, so as to allow the other investigators to actually study what is the ramifications of this? What are the ensuing cognitive deficit which are linked with removing this particular site out of the brain? A well known example would be of this patient called HM, Henry Molaison, who basically underwent a neurosurgery to get treated from epilepsy, but somehow their hippocampal area was removed during surgery and his memory formation was impaired for life. So this person could not form any new memories after this particular neurosurgery.

You can google up at Henry Molaison's or HM and you will find very interesting stories. Maybe some interviews with him as well on YouTube and Google.

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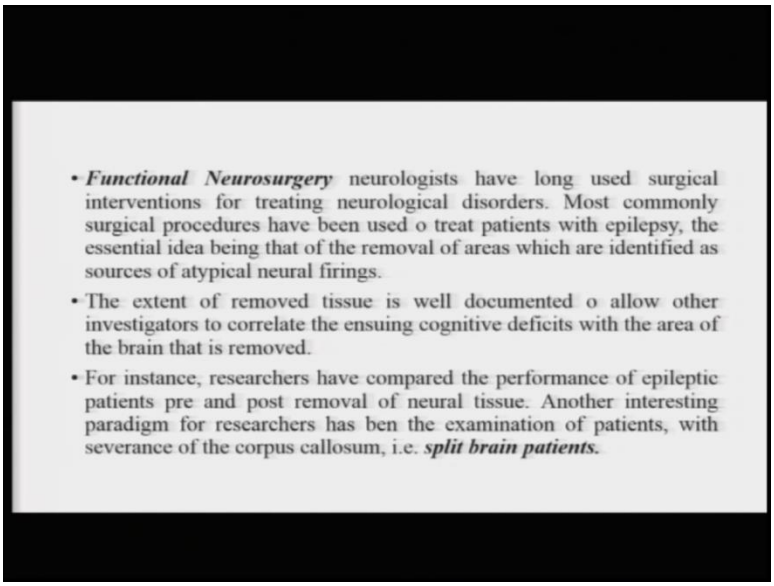

One of the other examples that we could take, functional neurosurgery, is patients who have had their corpus callosum severed. If you remember from the last class, the brain is consisted of two hemispheres, the left hemisphere and the right hemisphere. And the two halves or the two hemispheres are linked with each other using this bunch of external fibers called the corpus callosum.

In some patients, relieve them of epilepsy, the corpus callosum has been severed, and what it leads to is very interesting consequences in terms of the two brains almost functioning pseudo-independently of each other. These group of patients are referred as split brain patients.

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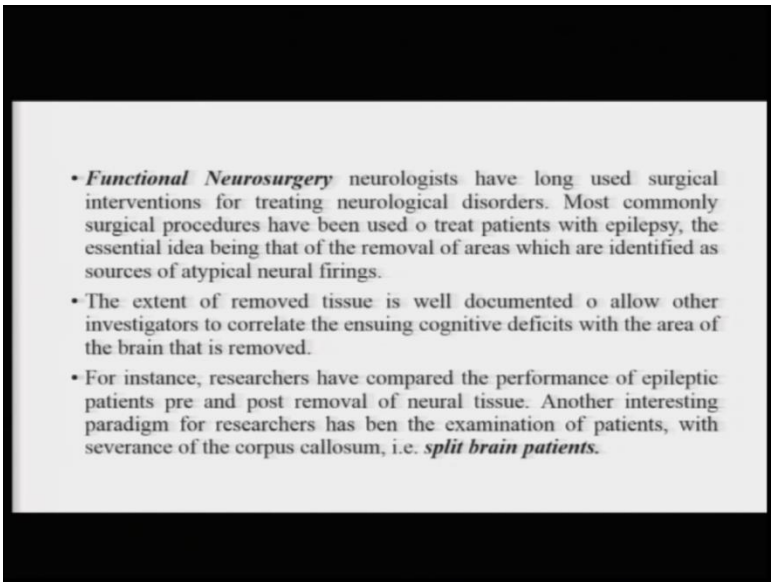

We will talk about them in the future classes of this course, but there are also very interesting group of patients and have led to very interesting insights about the organization of functioning in the human brain. Let us look at some of the methods that have been used to disrupt normal brain functioning. Now as I have been saying, well, there is merit, there is a lot of merit in studying atypically functioning brains.

Researchers have sort of looked to refine this thing, they have sort of looked at, okay, with natural lesions or natural disruptions, we will not have any control with respect to the extent of damage or to the site of damage, but if you can say, for example, selectively disrupt specific areas of the brain and then study them, that has its own merits and that has its own advantages.

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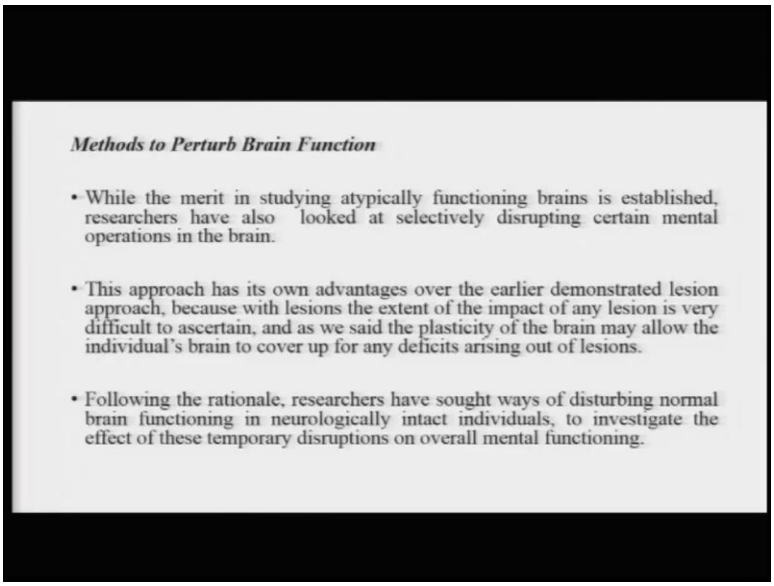

So this approach is advantageous because it allows the psychologists, it allows the neuroscientists to basically study exact deficits originating from disrupting the exact site in the brain. So researchers have been seeking out ways of disrupting or disturbing normal brain functioning in neurologically intact individuals to be able to investigate the effect of these temporary disruptions on overall mental functioning or even mental functioning with respect to specific tasks.

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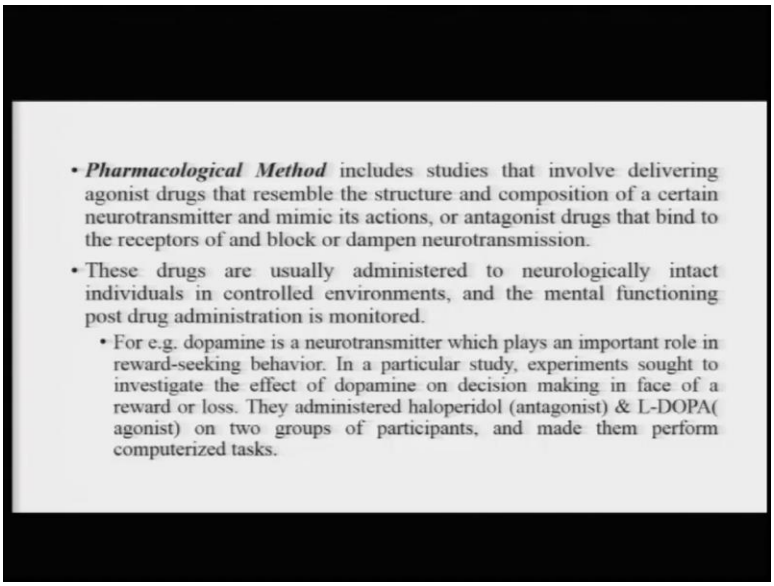

One of the methods is the pharmacological method. The pharmacological method basically involves delivering agonist or antagonist drugs to specific neurotransmitters, and basically to be able to study the function of, study the consequences of this kind of disruption of neurotransmitters.

These drugs are typically administered to neurologically intact individuals in controlled environments, as such that the mental functioning and then the mental functioning of the individual is observed. It is, as I said, pretty established that once these drugs, the effects of these drugs wear off, the brain can return to its normal functioning.

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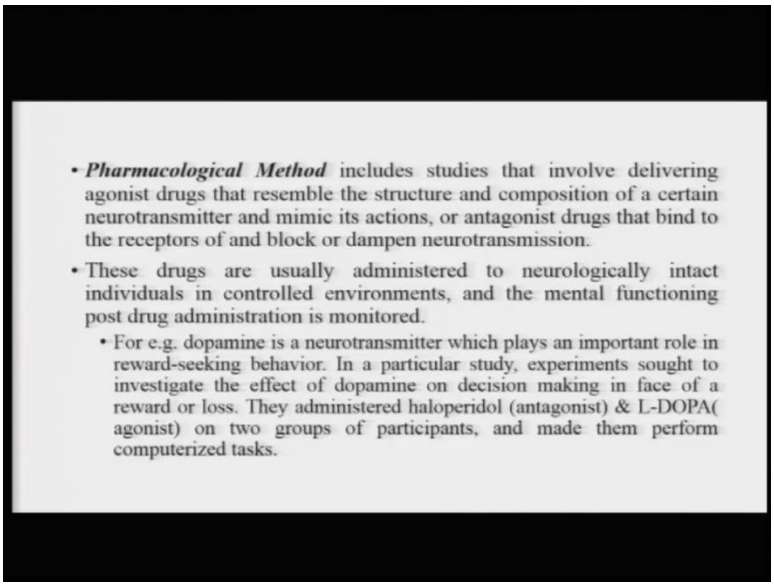

So, let us take an example. Dopamine is a neurotransmitters we have seen, which is, plays a very important role in reward-seeking behavior. So in a particular study, what they did was they had two groups of participants. One group was administered with haloperidol which is an antagonist drug of the neurotransmitter dopamine. So it basically it does exactly the opposite of what the neurotransmitter is supposed to do. And then there is an agonist drug, which is L-DOPA, which sort of mimics the function of how the dopamine would actually work.

And then these participants who were given computerized tasks. In these tasks, they were asked to choose between two symbols on each trial, and they had to choose the symbol such that they maximize their gains. So it was a gain versus loss trial. If you choose one symbol, you will maximize your gains, you will get some profit or you get some reward. If you choose other kind of a symbol, you will, you stand a chance of losing whatever points or money or something you have gained.

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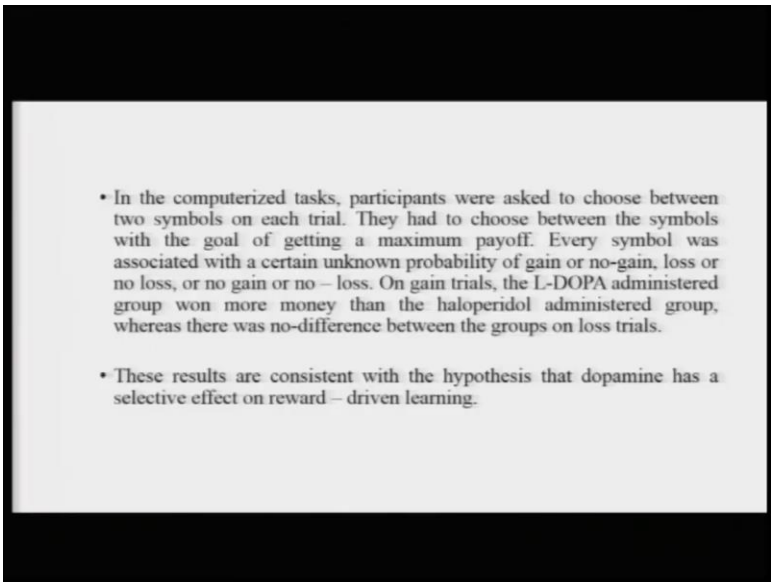

Now on gain trials, it was found that the participants who were administered with L-DOPA, which is agonist drug of neurotransmitter dopamine and resembles the way neurotransmitter dopamine would function, these participants want much more money than the haloperidol administered group, while there was no difference in the parts, in the performance of both the groups on loss trials.

So this tells us that dopamine is selectively responsible for reward behavior and it tells us that it has a very specific role in motivating reward-seeking behavior. That is one of the, that is probably one of the reasons why these participants who were administered with L-DOPA actually outperform the participants who were not administered with the L-DOPA, who were administered with an actual opposite chemical which was the haloperidol.

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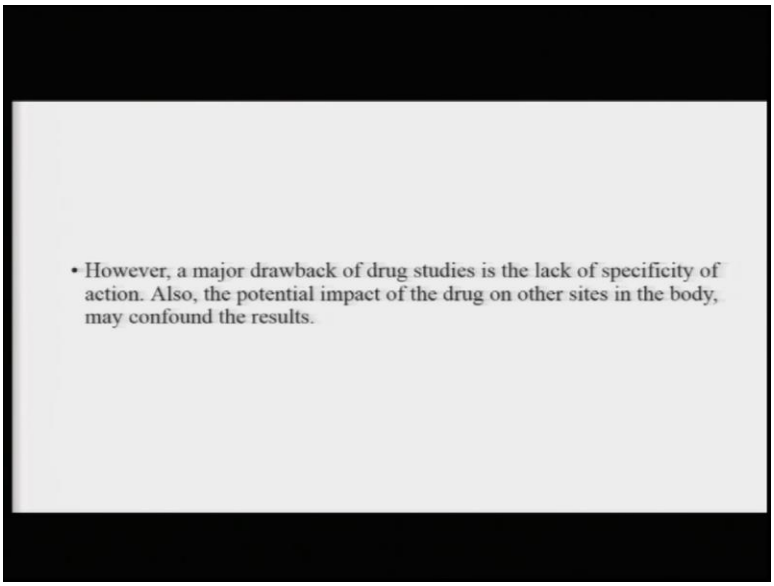

However, a major drawback of some of these drug studies is also the lack of specificity of action. So, you are not 100 percent sure of the fact that this particular drug is going to work in exact same manner and affect the exact same sites or will not have any other consequences or side effects on the entire brain and the body. So, there is a possibility of slightly confounded results here.

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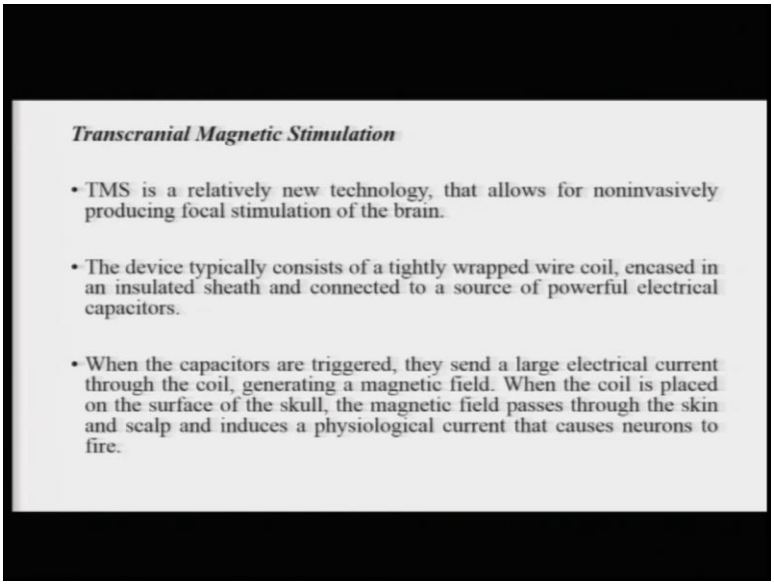

Another very very important very interesting new technology is TMS, it is not very new anymore, but it's a relatively new technology that allows for non-invasively producing very focused stimulations in the brain. It is a very interesting device, it consists of a tightly wrapped via coil, you can see the device here.

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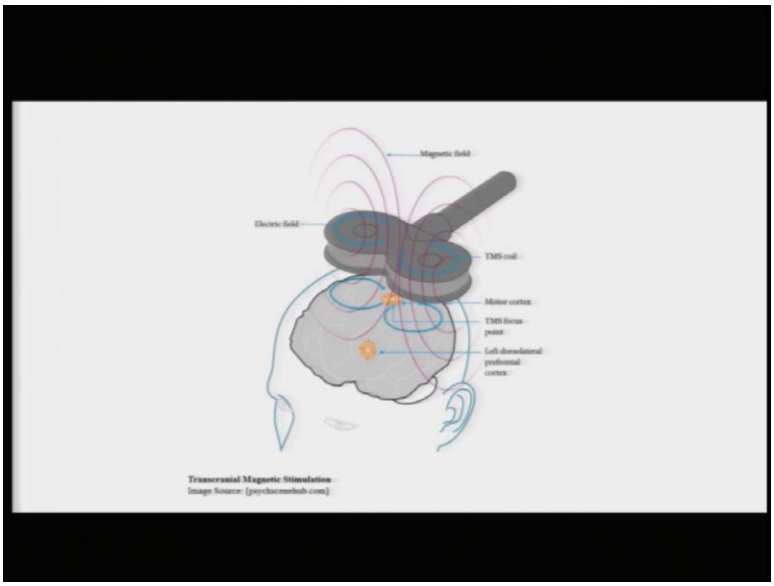

It has a very tightly wrapped wire coil and what basically happens is that the slight current is passed through this wire coil and it basically leads to generation of a magnetic field. This magnetic field can temporarily stimulate focal region of the brain basically at the centre as you can see, in the center that the motor cortex is being stimulated or let us say the left dorsolateral prefrontal cortex is going be stimulated.

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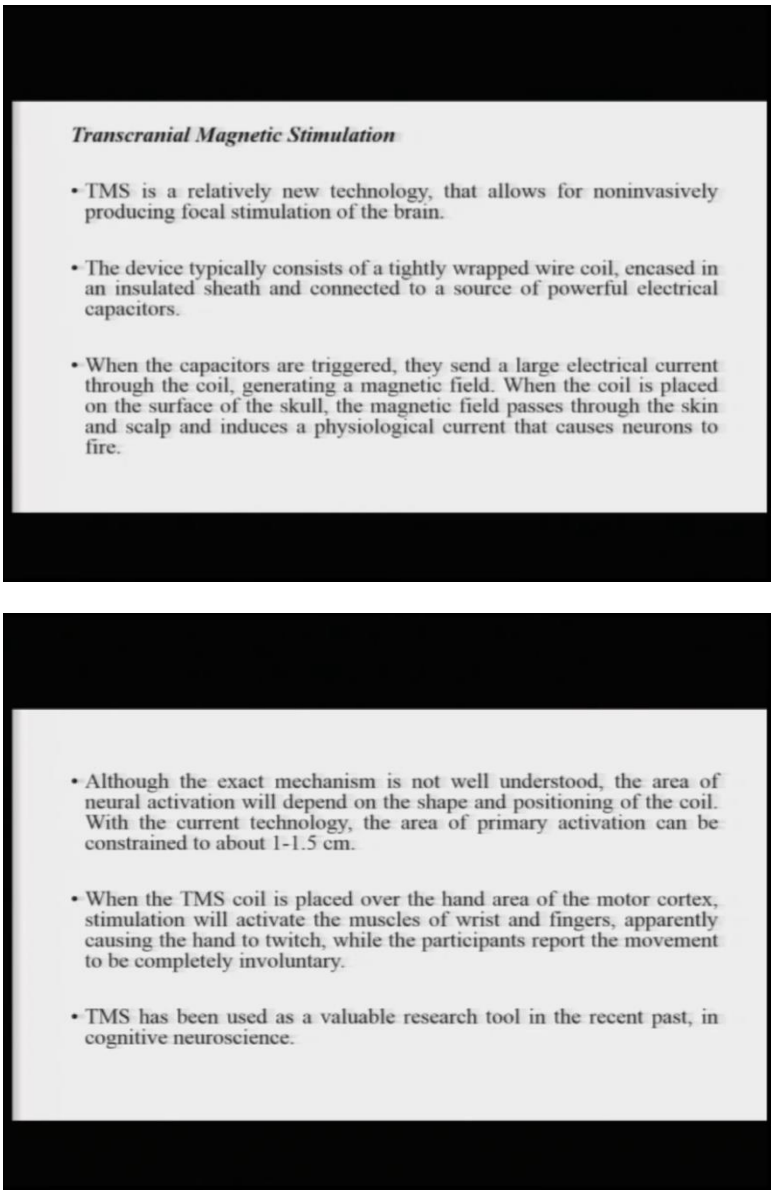

And once you stimulate a particular area, you can basically measure what are the consequences of that kind of functioning. And that is one of the reasons why TMS is, has become a very important, a very valuable research tool in recent past in cognitive neuroscience.

An example, another example could be, say for example, when the TMS coil is placed over the hand area of the motor cortex, it can stimulate the neurons that control the head area and it has been seen that participants actually visibly experienced a twitching of their hands, which they report is completely involuntary. So they have not really decided or they are actually controlling

their hands. But basically what is happening is that due to stimulation from the TMS, the neurons or the area of the brain that controls these movements is basically allowing for these moments to happen.

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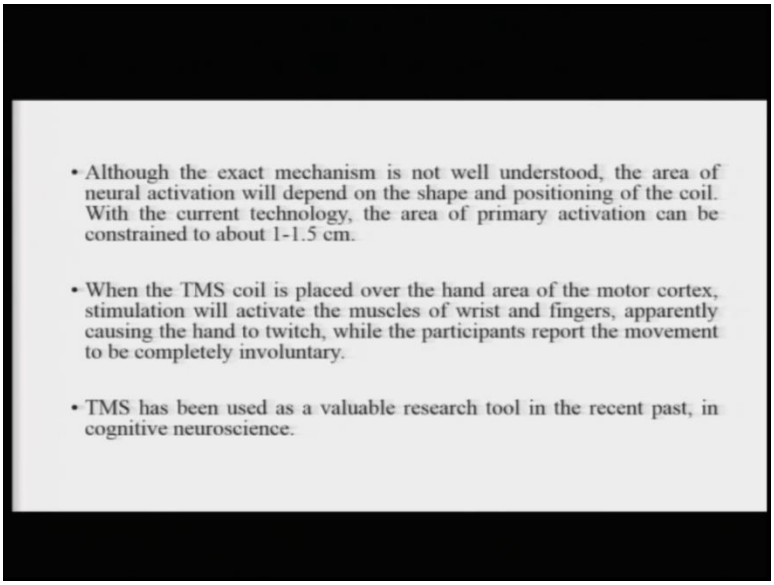

So this has many, many consequences, people have used TMS in various fields. We will talk about where all TMS has been used in the future classes. But interestingly, TMS has also been used in say, for example, treatment of patients who are depressed. Sometimes a good idea could be to stimulate the areas of the brain that sort of are involved in some kind of a pleasure related behavior and that can help pull out patients from their deep depressive episodes.

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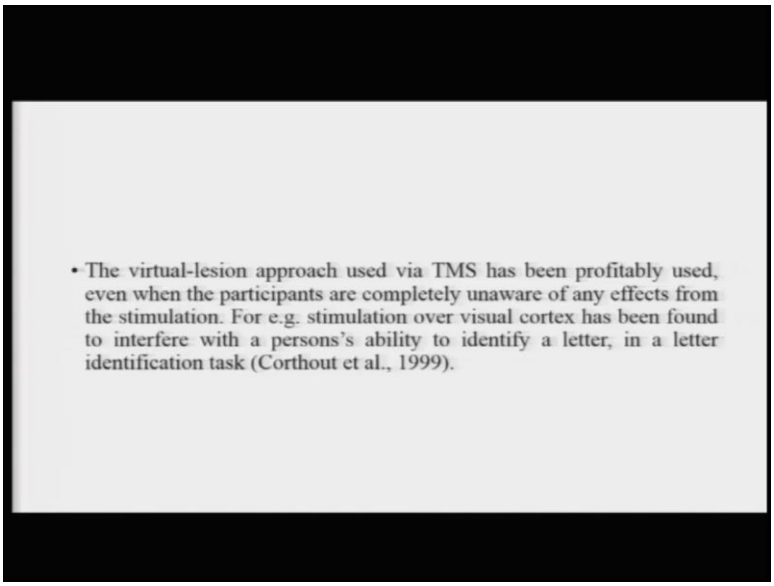

So, this virtual-lesion approach which has been used via TMS has been profitably used, even when say, for example, the participants are completely unaware of their effects. Even then these benefits have been sort of, for example, in a particular experiment with Corthout and colleagues in 1999.

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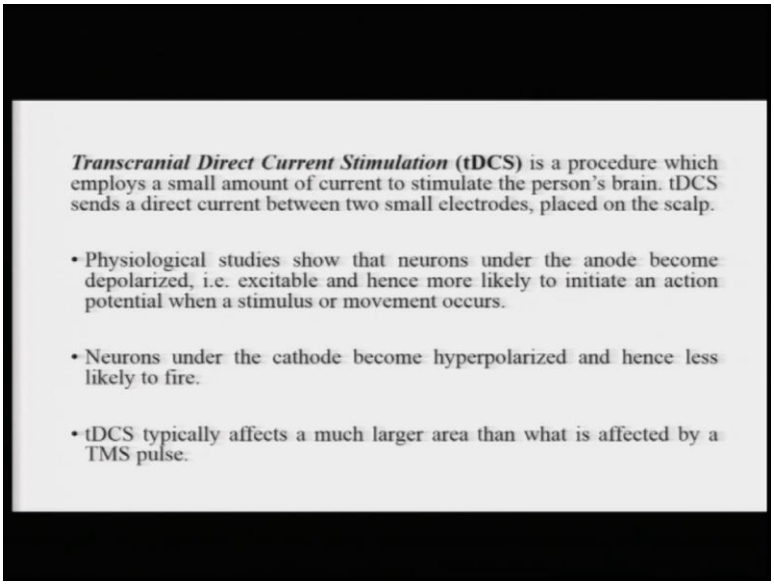

They asked participants to perform a letter identification task and then they simulated the brain or the visual cortex, and they found that disability would was interfering or influencing the

participants ability to identify the letters even though there was no apparent effects of TMS simulation reported by the parties. They were completely unaware of this happening.

The final method which has been used repeatedly and more so in the recent past, to stimulate the human brain is Transcranial Direct Current Stimulation. It is something which is, in some sense, very old as well, because people have been used, have been using electrical currents to simulate the human brain or simulate a person's brain historically as well, but there is a much more refined package or a way of using that particular technique.

So, tDCS basically involves sending a small direct current between two electrodes placed on the scalp, 1 is the cathode, one is the anode. As logical studies have shown that neurons which lie under the anode, they become depolarized or they become excitable. So, they start firing or they are say, for example, as soon as you introduce a stimulus, they will start firing or as soon as they detect the stimulus.

Neurons under the cathode become hyperpolarized, and they become less likely to fire. So, typically what you can do now, using this combination of electrodes, a cathode and an anode, you can sort of make certain areas more responsive or less responsive than they would usually be or with respect to control arrangement. And this basically can be used to test specific hypothesis about the functioning of the brain.

Now, it we will discuss a lot of experiments using these various techniques going further and then it will probably become much more clearer as to how each of these particular techniques have been used. tDCS by the way affects a much larger area of the brain than what is affected by the by the, by a TMS pulse.

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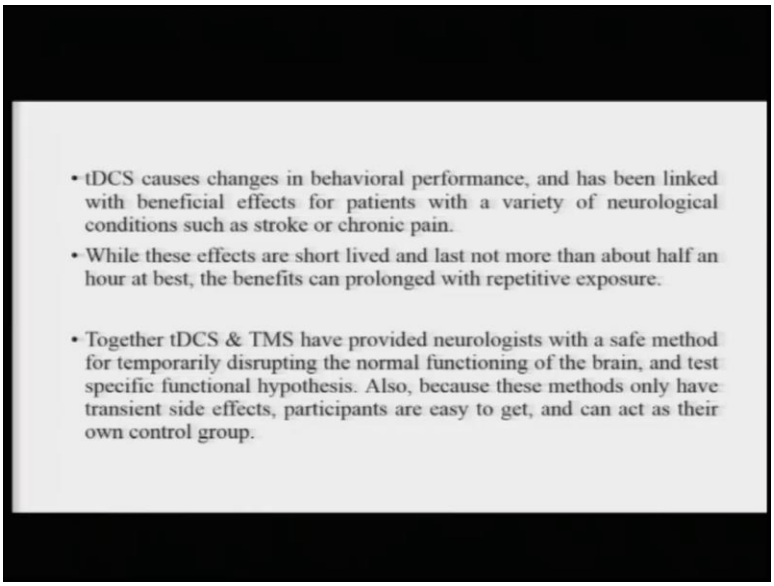

So, it has a slightly more advantage in terms of stimulation of a larger area of the brain or of controlling the larger area of the brain and tDCS has been shown to cause changes in behavioral performance and has been linked with the beneficial effects for patients with a variety of neurological conditions such as stroke or chronic pain, etc.

Now, these effects are typically short lived and they do not really last for more than half an hour or so, but they can be prolonged with the repeated exposure with the tDCS. So tDCS is also fast becoming one of the tools that are available to neuropsychologists, neuroscientists, psychiatrists in treating patients who come to them with different kinds of neurological, psychological disorders.

Now, together, if you see tDCS and TMS, they are not so much the chemical lesioning part or pharmacological part. They have provided neurologists with a very safe method for temporarily disrupting the normal functioning of the brain and then to be able to test very specific functional hypothesis, which area does what?

If I disrupt the functioning in the area A, and what are the consequences that I will get and you can sort of perform different permutations in combinations of these in order to get clearer and more specific hypothesis tested. Also, because these methods only have very temporary side

effects, they do not really cause a lot of discomfort to the patients. It is easier to get many participants for studies involving TCS, tDCS or TMS.

And also a very interesting caveat from this is that the participants can themselves act as their own control group before simulation and after stimulation. So, you can ask the participant to do some task before the simulation is done, and then do the task once the simulation is being done, and then the two can be compared and can actually help you test exact questions about say for example whether this area was disrupting or stimulating performance in this particular domain or not.

So, this is actually all about how to study or what will be the methods to study disrupted or atypically function human brain. In the next chapter, we will in the next lecture, we will talk about something else mostly about the structural analysis of the brain. Thank you.