Neuroscience of Human Movement
Department of Multidisciplinary
Indian Institute of Technology, Madras

Lecture – 57
Cerebellum Part – 6

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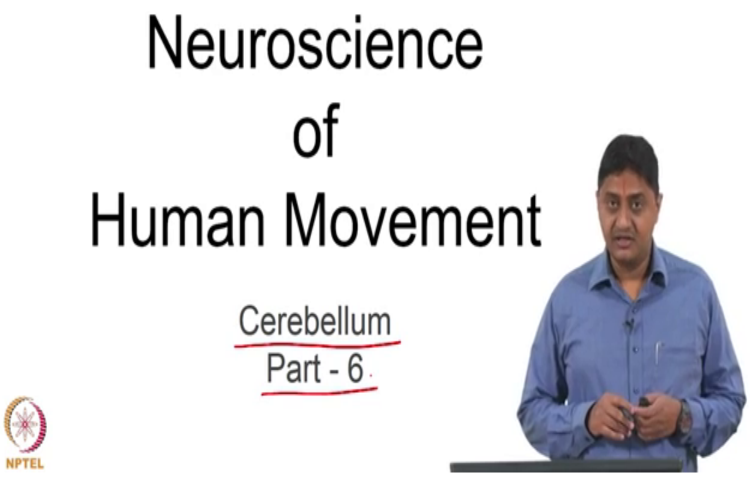

So, welcome to this class on Neuroscience of Human Movement. So, we will continue our discussion on Cerebellum. So, this is part 6 of our discussion on cerebellum.

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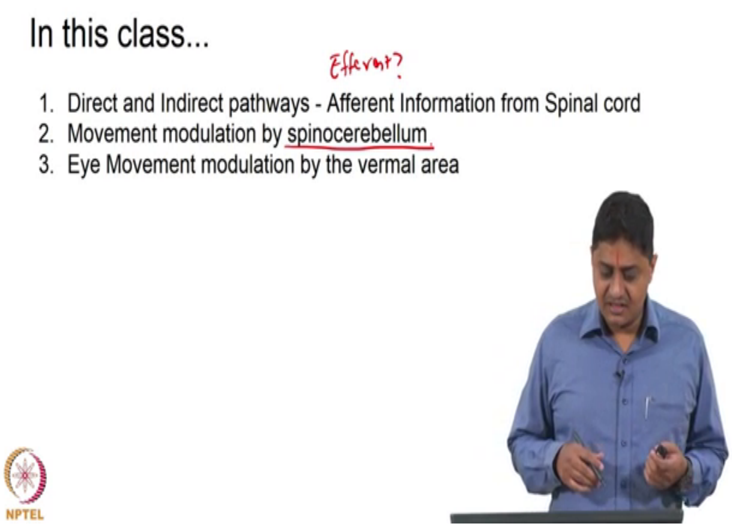

So, in today's class we will be talking about the direct and indirect pathways that bring in different forms of information afferent and efferent what kind of information from the spinal cord. I am putting a question mark after afferent for a purpose we will discuss that and how spinal cerebellum is responsible for modulation of movements and how vermis and the intermediate area or at least the vermis and the flocculonodular lobe are responsible for eye movements modulation. There are two types of eye movements that are presented circuits and smooth pursuits. So, this is basically the first class of at least two discussions on spinocerebellum ok.

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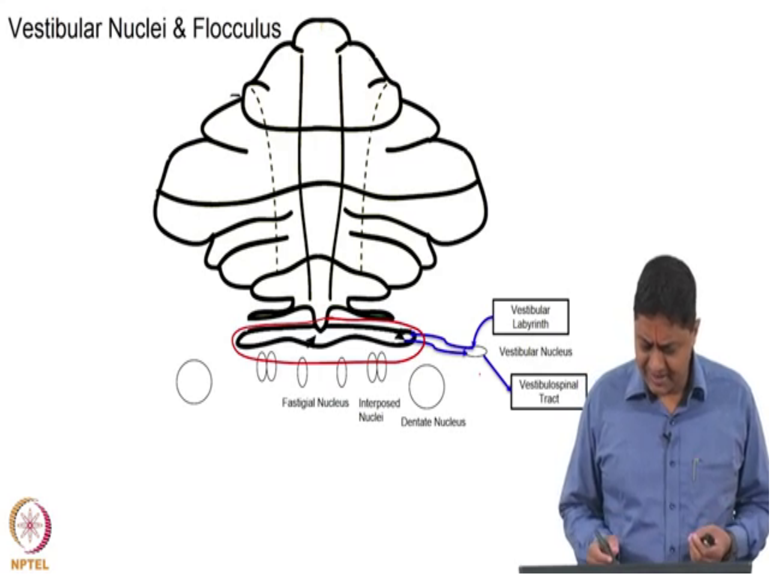

So, in the last class, we saw vestibular cerebellum. And we discussed this case, so that is the vestibular cerebellum, discuss this, this is the vestibular cerebellum. And we said that receives information from the vestibular labyrinth, the way are the vestibular nucleus. And then projects back to the vestibular nucleus, which is the equivalent of the deep cerebellar nucleus. And from the then the vestibular nucleus projects directly to the vestibular spinal tract to provide some form of corrections right. So, it is responsible for portion and balance in some sense right.

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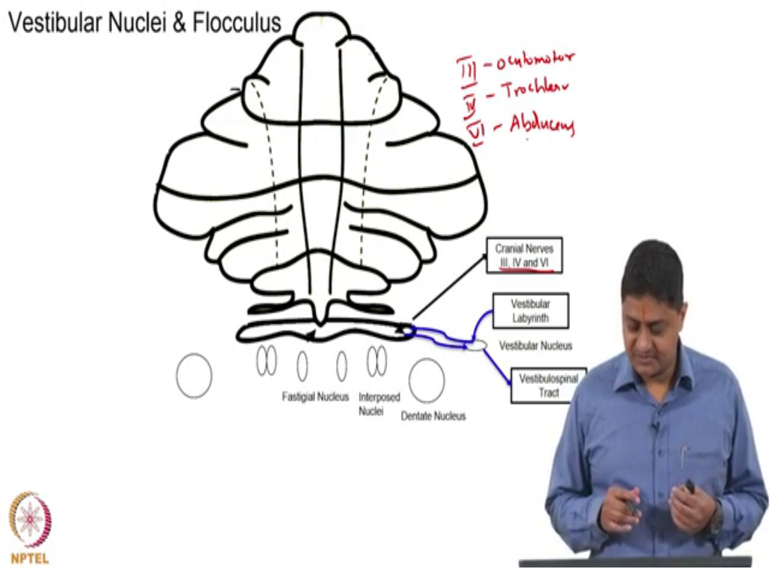

What also must have been discussed, but was left out is that the vestibulo cerebellum also projects to the cranial nerves, where the vestibular nuclei. So, what are these cranial nerves? These cranial nerves are 3, 4 and 6. What are these cranial nerves? Cranial nerve 3, 4 and 6 these are oculomotor, trochlear and abducens. These are cranial nerves that are responsible for control of eye movements, right. So, something that the vestibulo cerebellum also participates, ok.

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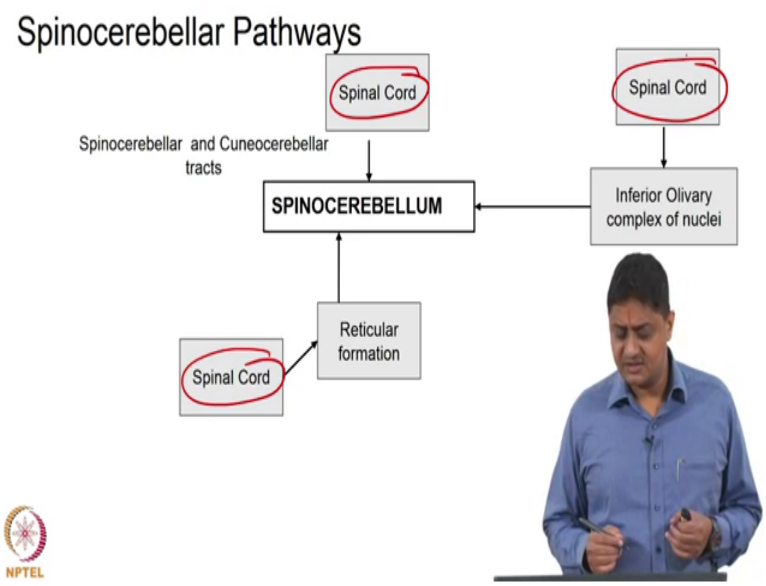

So, when discussing how spinocerebellum receives inputs, it receives inputs through multiple modalities. So, you say spinal cord in multiple places here. So, spinal cord, spinal cord, spinal cord, it plays in three different places for convenience actually. So that means, the spinocerebellum this is input through multiple pathways.

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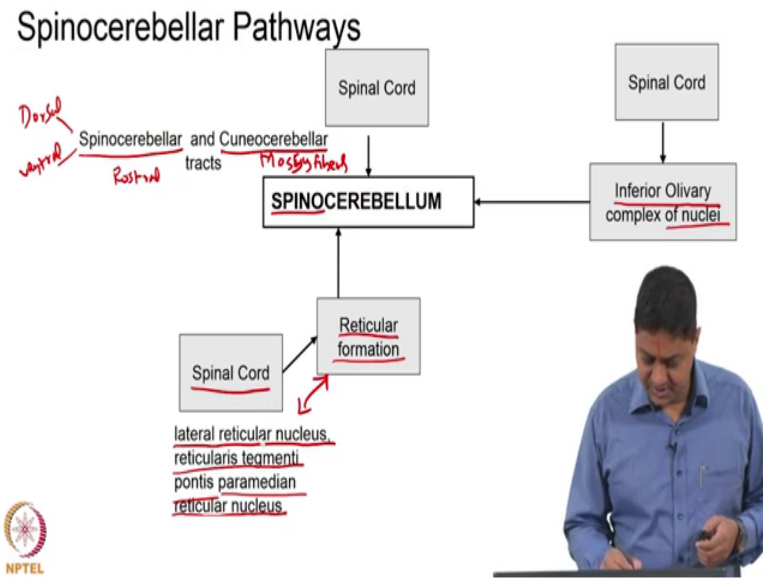

One is one of the most important pathways is the cuneocerebellar and other spinocerebellar tracts. Actually there are two such tracts, we will discuss in the future slides. Spinocerebellar and cuneocerebellar tracts, these are also called as varied layers the there are other names, other than these there are dorsal and ventral spinocerebellar pathways.

So, these send different forms of information either that may be afferent or sensory information or efferent or in other words commands that are sent to the motor neurons are also copied to the cerebellum that might give you an idea of why or what could be the purpose or what could be the function of the cerebellum. We will continue that in the next few slides, this discussion.

So, one source is the spinocerebellar, which are divided into two different types basically dorsal and ventral and cuneocerebellar and rostral spinocerebellar tract. So there are multiple pathways that project from the spinal cord directly into the spinocerebellum, so that means, these neurons become mossy fibers. And project to the vermeil and the intermediate zones in the cerebellum or the spinocerebellum.

These are the mossy fibers that project to the spinocerebellum right. Also spinal cord projects to the inferior olivary complex or inferior olivary complex nuclei, from there, obviously there is projection to the spinocerebellum. Also spinal cord projects indirectly more indirectly, where the reticular formation, where the following nuclei, these are the lateral reticular nucleus, reticularis tegmenti, pontis and paramedain reticular nucleus. There are three nuclei through these are nuclei of the reticular formation through these three nuclei, it projects to the spinal cord ok.

So, these are the various inputs that are received by the spinocerebellum. So, the spinocerebellum this is inputs from at least from three different sources, directly from through the spinocerebellar tracts and the cuneocerebellar tracts or dorsal and ventral spinocerebellar tracts and the cuneocerebellar tract and the rostral spinocerebellar tracts right. And where are the reticular formation, spinal cord, reticular formation and from reticular formation to the spinal cerebellumand where are the inferior olive ok.

So, these are the various inputs to the spinocerebellum. There is a reason, why this is called as the spinocerebellum right, because it receives information from the spinal cord and processes this information. And probably outputs to the spinal cord, but let us remember that cerebellum does not directly project to the spinal cord, but rather it is projections are indirect. This is something that we have discussed earlier and so that is so then, we will have to know how the cerebellum projects back to the spinal cord, how does it control or correct movements right. So far we have seen the inputs, just to erase this ok.

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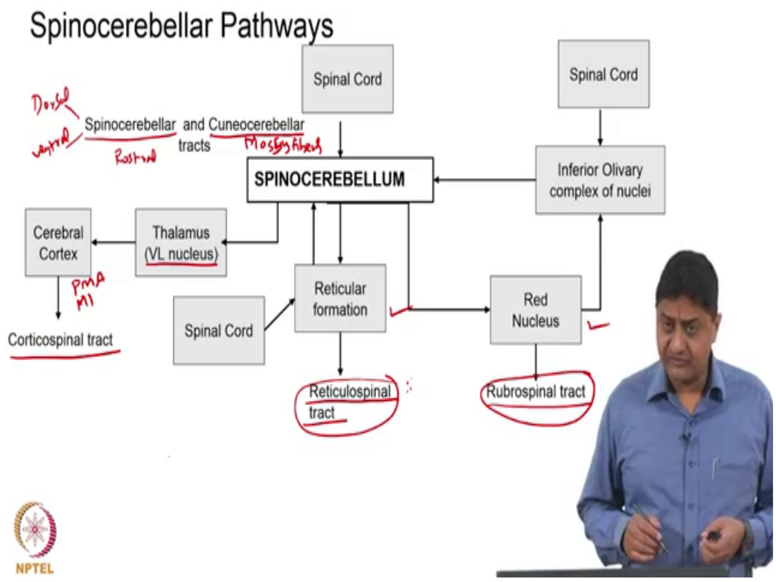

So far we have seen the input, what are the outputs? So, what are the outputs right? One output is from the spinocerebellum to the reticular formation and it projects back to the spinal cord, where the reticulospinal tract ok. The other output is to the red nucleus and from the red nucleus to the rubrospinal tract. And the red nucleus also projects to the inferior olive. The other output is to the ventro lateral thalamus and from the ventro lateral thalamus to the cerebral cortex or the motor areas of the cerebral cortex.

This is the pre motor area and primary motor cortex. The question is if you are anyway going to project to the cerebral cortex and control via the corticospinal tract, so that means if at anyway going to perform, the more fined controller or modulate more finally, why have these, why have reticulospinal, rubrospinal this? You know and also, what is not shown this is the case of the spinocerebellum. In the vestibular spinocerebellum also there is projection to the vestibular nucleus and from the vestibular nucleus back to the spinal card via the vestibular spinal system.

Note the outcomes of these are not expected to be fine right, they are going they are expected to be quick. Relatively fast responses, but not necessarily fine or maybe there are those parts of the body that require fined control that are not projected by these region such as the reticular formation and red nucleus right. So, there are multiple ways in which the spinocerebellum outputs. So, there are multiple ways it in which it receives inputs. And there are also multiple ways in which it sends its outputs.

What are the various inputs one more time, the major inputs are the spinocerebellar tracts. These are the dorsal and the ventral spinocerebellar tracts and cuneocerebellar tract and the rostral spinocerebellar tract. And another in major input is indirectly through the reticular formation. And we said what the nuclei of the reticular formation that receive this sort of input. And another in input is where the inferior olive right. These are the major inputs to the spinocerebellum.

And what are the major outputs? The major outputs are via the reticular formation and red nucleus. So, the projecting respectively to the reticulospinal tract and the red nucleus projecting to the rubrospinal tract and the other output is via the thalamus, the ventral lateral nucleus of the thalamus and from there to the cerebral cortex or the motor areas of the cerebral cortex and to further from the cerebral cortex from the motor areas to the corticospinal tract. So, these are the major inputs and outputs of the spinocerebellum right, so right.

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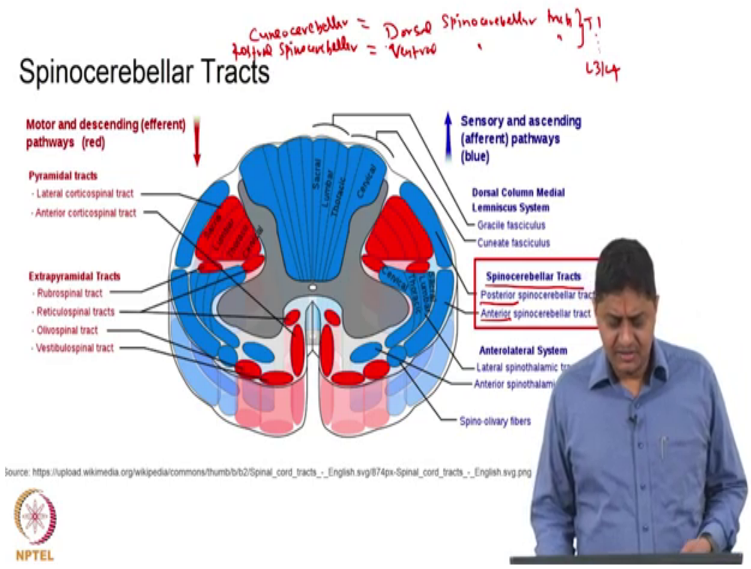

So, what are the spinocerebellar tracts that we are talking about? What is presented here is one representation of multiple inputs and outputs. Here we are concerned only about the spinocerebellar tracts. So, this is the posterior spinocerebellar tract and this is the anterior spinocerebellar tract right. So that means there are also called as variedly as the dorsal and the ventral spinocerebellar tracts ok.

And there so these so the dorsal and the ventral spinocerebellar tracts start from the vertebra T 1 and continue until about L3, L4 right. Then the question is what about the vertebra C 1 to C 7 right. Because, in our discussion on spinal cord and vertebral column we said C 1 to C 7, then the thoracic vertebra, then the lumbar vertebra, sacral vertebra and so on, and coccyx . Is it not? This is our this is the add up right. So, if the dorsal and ventro spinocerebellar tracts are starting from T 1 continuing until L 3 L 4.

So, basically they are bringing information from the thorax and parts below the thorax right, for example the hind limbs. What about the forelimbs and parts above the thorax, for example, the neck and the hand and arms right. Those are not about by cuneocerebellar pathway. And the rostral spinocerebellar pathway that is the name of they are the analogs these two are equivalent and these two are equivalent. The question is what are the sorts of information that is a brought by these.

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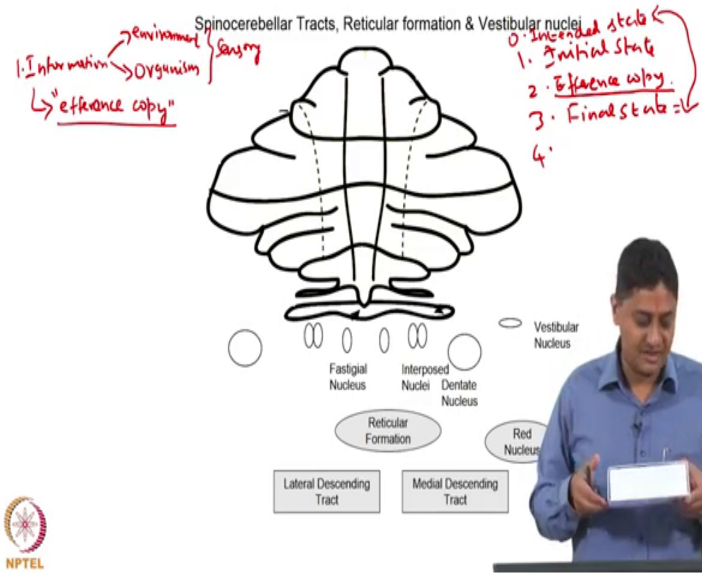

I will discuss some of these topics in this slide and we will continue with the pathways in a bit. So, I will discuss these in this slide. So, what are the various sets of information? First is information about the environment. What is going on in the environment? So, basically the environmental information and the other information is from the organism.

So, the organisms information like for example, there are the various parts of your body, what is the relative position of your body parts with respect to each other for example. So, you know the environmental situation, you know the relative position of the body parts also the other. So, these are sensory information. Is it not? So they are brought about by the dorsal side of the spinal cord. So, basically they are brought about by the dorsal spinocerebellar tracts.

Also there is information that is sent to the spinal motor neurons that are sent to the cerebellum as well, so that means alpha and gamma motor neurons receive commands from other systems. A copy of these commands is sent to be cerebellum. This is an important, this is a crucial principle called efference copy. From this I know not only the state of my body I also know what is a command that is given to the particular lumbar, but the particular body part or to the particular muscle for example.

So, from this I can compute, I want to make this moment. This is the environmental condition, this is how my this is where the parts of my body are located and this is the command I have given. Now, what is a actual output? The actual output also is measurable right is also something that I know once again from proprioceptive information.

So, I know the I am making an attempt to perform the moment, then I can compare this is the sensory state, the original earlier state. So, basically initial state I know. I also know command given, what is the command given by command given I mean the command that is given to the muscle is copied to the cerebellum right that is the efference copy. By the way if you give a command, does it does not mean that you will be in a position to you exactly execute, what is intended right.

So, you also know the final state. What is the goal? The goal is also you know the intended state means you know the initial state, you also know the intended state. How do you know the intended state? Actually the intended state is known through other pathways not discussed in this class, we will discuss in future classes. But, so I you know what I want to do, I know where I am to at this moment, I know what is the command that has been given, I also know what is a final state.

The goal is to ensure that the final state is the same as the intended state. These two must be the same, if they are not the same, then there must be a correction that must be made. Is it not? Approximately, I am presenting as if the cerebellum is a computer and it follows a set of rules or algorithm. Actually this is not true. Approximately, this is what is going on. The system is trying to compare, the difference between the actual state and the intended state and how are whether the command that is given is able to achieve the intended state right. So that how do you know?

So, crucial to this is the information on that efference copy or the information that is given to the muscle. This is important because, I have an object that is sometimes. We may have an object that turns out to be heavier than expected or the physics is different from what is expected. Then you have to make appropriate corrections to the command that you have you are giving.

Suppose, imagine that there is this box ok. And you know, you are not able to see what is inside this box. So, this box you are not able to see what is inside. Let us say that this box is kept on a table, suppose it is a table and there is a box kept on the table, now saying lift it. You are from your observation and previous experience you think ok, this is a box that is made of cardboard, you are able to see that this is made of cardboard.

And you would expect it to be half mass about say 100 grams or less. Reasonable expectation or you would expect that there might be some object that is kept that might be a little more than 100 grams, maybe a few hundred grams. Let us suppose, it is completely filled with led or very heavy objects (Refer Time: 19:12). And it weighs several kilograms and I am asking just take it with one hand just lift it right. As you are lifting, you realize that its mass is much greater than what was originally thought of what you originally expected. Then what you do? There are corrections that are made how do you,

so, initially you expect of particular mass.

And the command that is generated to lift or to that lifting muscles, the muscles that perform the lifting action receive particular commands. And that command is not able to execute the task that command is not able to achieve the intended state. Then you realize this is the command I gave, it is not able to bring the or make the final state similar to the or same as the intended set, then what you do? You make corrections right. Once again a very crude example of what is going on what is actually going on is way more fine than what was described now ok.

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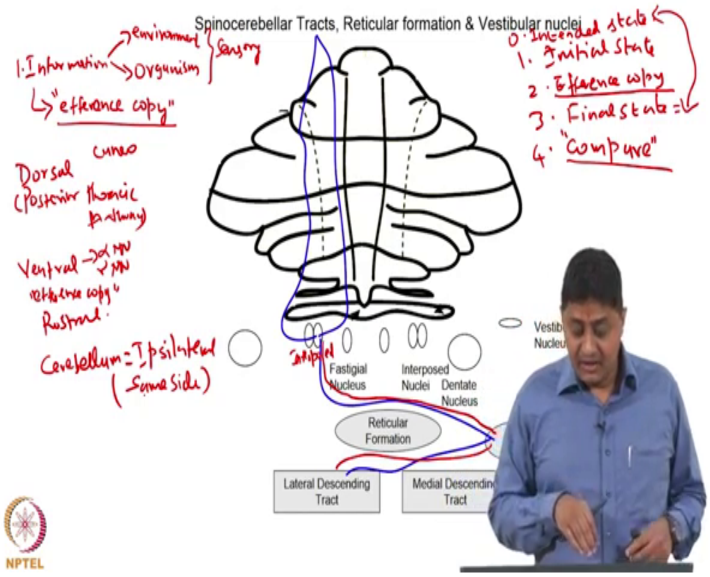

Other the other than this, so based on this we know that so we know that the cerebellum or at least the hypothesis is that the cerebellum somehow compares these various states and then changes commands appropriately. So, how does it change the command? By the way if it changes the command, it is not going to be able to directly communicate that to the as final cord that is going to be able to do that via only the reticulospinal pathway or the robro spinal pathway or via the ventral lateral thalamus to the cortex and where the cartico spinal pathway right, we have discussed this.

So, the information is coming from spinocerebellar tracts, what are these tracts. We have said, what these tracts are these are the dorsal spinocerebellar tracts, this is also called as the posterior thoracic nucleolus or the posterior thoracic system or the posterior thoracic pathway brain. And ventral whenever we say ventral we are immediately reminded that the ventral part of the spinal cord is responsible for motor functions right.

So, same input as alpha motor neuron, gamma motor neuron or the spinal motor neuron inputs are the efferent efference copy. So, this is actually afferent to the spine to the spinocerebellum, this is actually afferent to the cerebellum, but this is bringing an efference copy. So, I am giving a command, let us suppose I am giving a command or I am giving a request to one of my students, I am copying it to somebody else right, to ensure that they are doing that.

And they are analogs basically the cuneo and the rostral spinocerebellar pathways right. And it is known now that this is happening via the that these two perform different actions by experiments or animals. For example, if there is a (Refer Time: 22:35) cat right and if it is walking it is there, you measure that there is rhythmic activity of both the dorsal and the ventral pathways. When the dorsal roots are cut, the dorsal pathway remains become silent whereas, the ventral pathway continues to produce this rhythmic activity right. So, these pathways start from the spinocerebellar tract and end at the interposed nuclei.

At what are this interposed nuclei, emboli form and globos nuclei, is it not and from their project to the red nucleus and to lateral descending tract. Please note that is crossover of some. So, this is where the superior peduncle. So, there is crossover of these tracts from one side to the other side. And from the red nucleus back to the descending tract there is one more crossover.

We said early on that the cerebellum control is ipsilateral or the same side right that does not necessarily mean that all the projections will also have to be on the same side. For example, in this particular case we saw that the crossover is happening two times. Once it crosses from the left side to the right side and then from the right side back to the left side So, there is a double crossover ensuring that the same side of the body is still being controlled or modulated by the cerebell right also through the reticular formation inputs from the reticular formation through the fastigial nucleus right and to the vestibular nucleus and the vestibular spinal tract.

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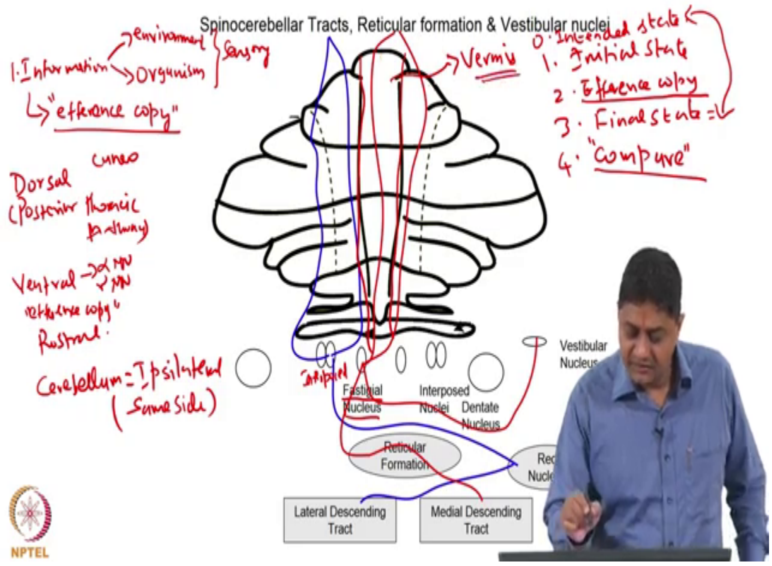

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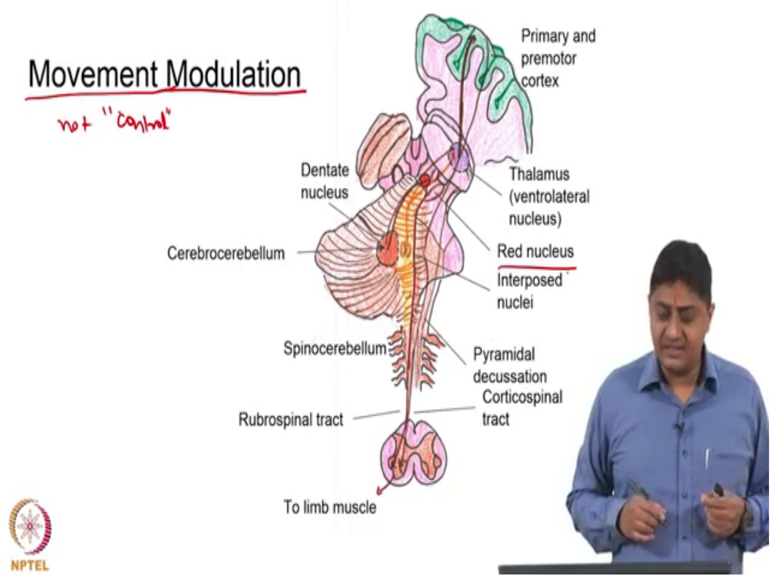

We say that the cerebellum modulates moment or it performs initiation and modulation, but rather than not control per say, but rather modulation. This is because of course this is because that it does not directly project to the spinal cord. But, also let us remember that the spinal neurons receive inputs from multiple descending systems from red nucleus, from reticular formation, from the cortex, from various such systems, from vestibular nucleus and so on and so forth.

So, the inputs from the cerebellum can only modulate the outcome to some extent, but not control. What is the difference, the difference is that when you mean control, you are talking about moment to moment control or finest of control right. Of course, such control or go is going to be possible from the cortical regions, but not necessarily through the regions that are other regions such as the red nucleus, reticular formation etcetera right. So, there is there is only movement modulation, there is performed by the cerebellum not necessarily control. Also it is known that the middle region that the more medial region of the cerebellum is called as the vermis, we saw that early on.

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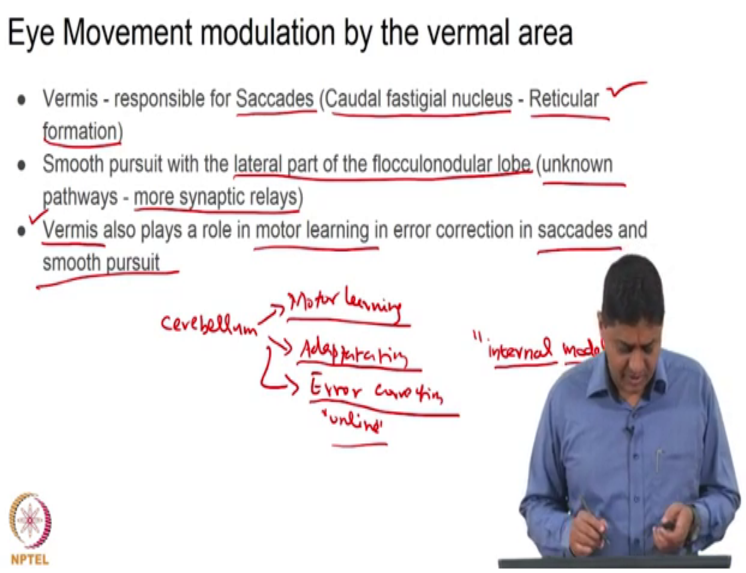

It is known that the vermis is believed to be responsible for control of saccades. Some information about the pathways involved are also known, it is believed that this is through the caudal fastigial nucleus and reticular formation or the saccade generator circuit that is located within the reticular formation right. Also we saw in the previous class that smooth pursuit is performed with the help of the lateral part of the flocculonodular lobe. The exact pathway remains unknown the exact path way, but it is definitely at least what is at least known is that there are more synaptic relays than this case.

So, saccades have a smaller number of synapses, whereas smooth pursuits have more number of synapses. And that makes sense right, because you know saccades are fast control or fast changes are sudden changes, where a smooth pursuit involve moment to moment control more smoother. So, of course the exact pathway continues to be elusive we have not been able to identify that.

Also it is hypothesis that vermis plays a crucial role in motor learning. What is motor learning, motor learning refers to this phenomenon where there is a correction in errors that are made either in the short term or in the long term. Especially, when it comes to saccade and smooth pursuit correction error corrections, it is believed that vermis plays a crucial role.

So, actually it turns out that the cerebellum performs two forms of error correction. One is called as motor learning, the other is called as adaptation, the other is simply called as error correction, this is online error correction. So, motor learning refers to this phenomenon, where skills are learned over practice are through extensive practice over several days or months or years this, so refers to this long term changes right.

Adaptation on the other hand in general refers to short term or learning of more of associations that can be learnt or unlearn or re learnt right. Online error corrections of those that are really short term that are that happened now and that is it. So, cerebellum probably participates in all these. And then a question is how does the cerebellum do that is, because that is through it is at least a controversial hypothesis in the function of the cerebellum is through the use of internal models. This is an interesting, but controversial hypothesis that the system somehow controls specific aspects of movements and learns and unlearns specific aspects are through these internal models ok.

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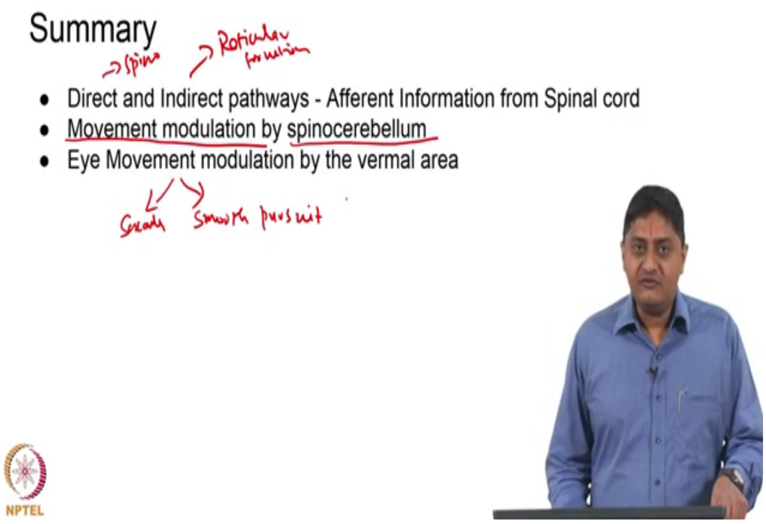

So, in summary we have seen direct and indirect pathways. Direct or spinocerebellar pathways, indirect are those that go where the reticular formation and how movement is modulated or controlled by the spinocerebellum and how eye movements are modulated by the vermis, what do you mean by eye movements, saccades and smooth pursuit. So, with this so with this we come to the end of this class. We will continue the discussion on spinocerebellum in the next class.

Thank you very much.