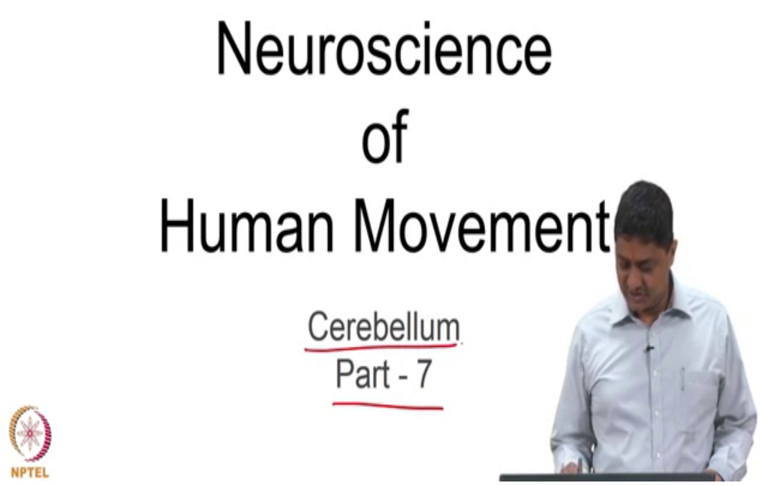
Neuroscience of Human Movement
Department of Multidisciplinary
Indian Institute of Technology, Madras

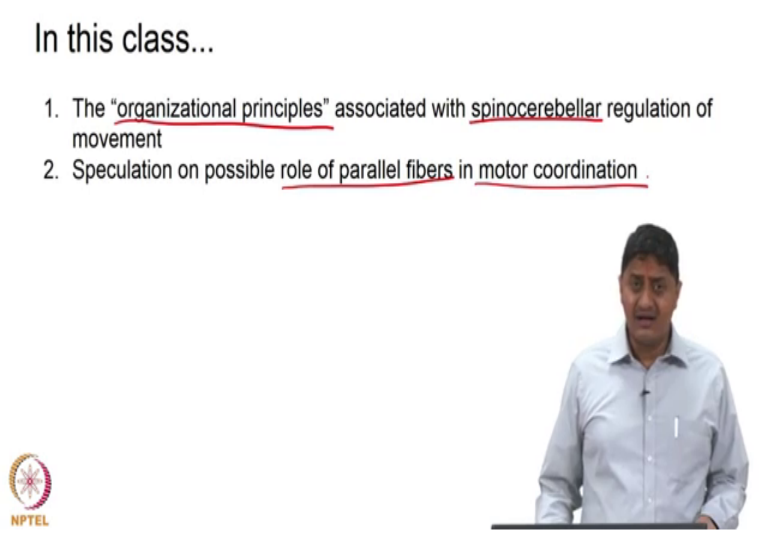
Lecture – 58
Cerebellum Part – 7

(Refer Slide Time: 00:15)



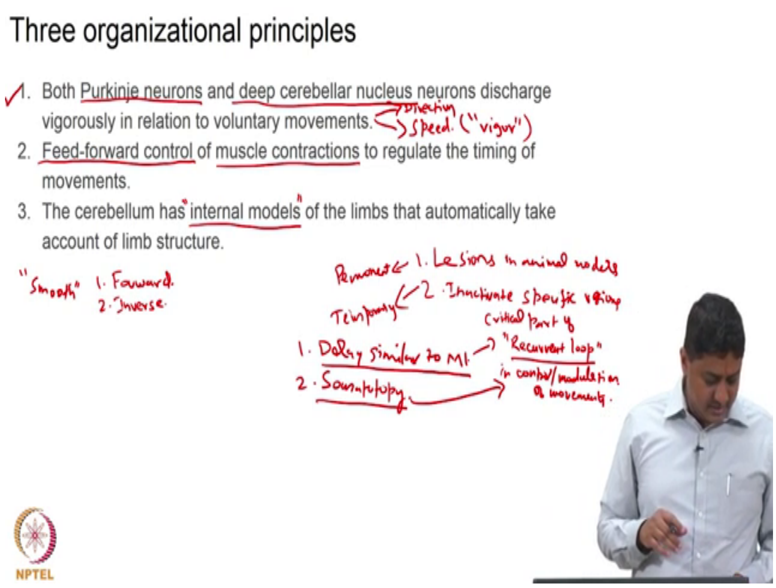
So, welcome to this class on Neuroscience of Human Movement. So, this is part 7 of our discussion on Cerebellum right.

(Refer Slide Time: 00:21)



So, in this class, we will continue our discussion on spinocerebellum. In the last class, we introduced the notion of spinocerebellar modulation of moment it is we said that this is modulation rather than control all right. So, in this class, we will discuss the organizational principles associated with the spinocerebellar modulation or regulation of movements. And what is the possible role of parallel fibers in motor coordination, because we have 100 billion of these what could be its role, what could be the role of these large number of neurons 100 billion temperature, (Refer Time: 01:06) its role in motor coordination and motor function.

(Refer Slide Time: 01:09)



The following are the three important crucial organizational principles, how are this learned. Fundamentally, it is important to note how these are learned. First these are learned from animal models, so whenever we say animal models, there are multiple ways in which experiments could be performed on animals. These one obvious way, and then important this lesions on animal models.

And the second one is it is possible to inactivate specific regions of the cerebellum using method such as cooling in activate specific regions. This may be cerebellar cortex; this may be deep cerebellar nuclei. By this, we could simulate a situation in which that particular region or the, are the set of neurons that are affected by this cooling are not functional for the particular period of time And then observe the effect of this effect of this perturbation on the system. Now, obviously lesions are permanent damage or permanent effects, whereas cooling has less permanent or temporary effects, is it not obviously.

So, from these animal models and studies, we have learned a few lessons. And these lessons are listed here. And these are first is that Purkinje neurons and deep cerebellar nuclei or neurons in the deep cerebellar nuclei discharge vigorously in relation to voluntary moments. What does that mean, it turns out that when voluntary movements are happening at just before voluntary movements are happening. It turns out that Purkinje neurons and deep cerebellar nuclei neurons discharge or produce activity or manifest activity that resembles the activity in the motor cortex in at least two different ways.

First is that the delay is similar to motor cortex. So, this is surprising, because we said cerebellum does not directly project to spinal motor neurons. We have said this earlier, we will continue saying this is a crucial principle. Cerebellum projects to other motor areas, which further project to spinal motor neurons and control movements. In that sense, we said even in the previous class, we said that the cerebellum only modulates movements, and does not control moments per say.

However, here I am saying that the delay of the or the time delay between the activity of these neurons, the Purkinje neurons and deep cerebellar neurons, and the action and the voluntary action or the movement activity or the muscle activity that delay is similar to the delay between M 1 neurons and muscle activity. This is about 100 milliseconds give or take right or maybe even a little less that is surprising, because cerebellum must project to some other motor area, and then project to the spinal motor neurons, and then you know modulate moments, whereas M 1 directly can project to spinal motor neurons or maybe through inter neurons. But M 1, it is known projects to the spinal cord through the cortical spinal tract, and through the pyramidal tract, we know these things right.

So, when I say that the delay is similar to M 1, then it implies. Then we are asking the question what does this mean, what could this mean, does that mean that cerebellum is the other cerebrum, does that mean that the cerebellum performs functions that is similar to motor cortex? The answer is no, it turns out that the cerebellum forms a recurrent loop right, the cerebellum forms or at least it forms part of a recurrent circuit synchronous with motor cortex to modulate movement. So, it is an important part or a crucial critical part of a recurrent loop in control and modulation of movement. So, it is not controlling movements like the M 1 does, but it forms an important element of a recurrent loop in this process in the control of moments, so that is one.

2 is somatotopy, we have seen this earlier that there is somatotopy in the primary motor cortex. We have seen this, we have discussed this is the penfields map. We have discussed in great detail to what extent is the primary motor cortex somatotopic etcetera right. It turns out that the deep cerebellar nuclei are also somatotopic, but slightly different from that.

The anterior portion contains are the anterior parts contained the tail, and the posterior parts contained the head; in other words, it is upside down right and also that the medial parts the medial regions contained the limbs, and the lateral regions contained the truck. So, again it is turned side words right. So, this somewhat so projections from the Purkinje neurons to the deep cerebellar nuclei is somatotopic. So, there is topographical organization similar to M 1.

So, once again this raises the question does this control movements, the answer is that no once again the same we have to come we come to the same conclusion that you know the cerebellum participates or at least is a critical part of the recurrent loop in movement modulation. So, this is what we learned from the first lesson. This is that Purkinje neurons and deep cerebellar neurons, their discharge is vigorous in relation to voluntary movements. Sometimes very comparable to motor cortex, yet we only believe that their role is in modulation of movements.

And also then what does it control, what does it modulate. When you say modulation of movements, what does it modulate, at least it is now known that it modulates a direction of movements, and it modulates the speed of moments. So, when you say speed, we are talking about some form of movement vigor some form of vigor right, how fast you can know right that is one.

The second important lesson that we have learned is that the cerebellum anticipates the movement. And the contractions that are required to perform the moment. So, in that sense if I have to reach a particular point at a particular point in time, the appropriate muscle contractions that are required or anticipated by the cerebellum. How does the cerebellum do this that is a controversial question that takes us to the second that takes us to the next lesson, but first this one.

So, the cerebellum is believed to perform this function of anticipation by feed-forward control of muscle contractions, thus regulating timing and sequencing of movements. Now, we will discuss some examples in the next few slides. So, there is anticipatory or feed-forward control of muscle contractions, so that appropriately time the sequence of movements are produced this is crucial right. At a broad level, at least the following can be said you do not wear the suit and then go to bath right. So, there is a sequence in which these things are to be done, but that is at a very broad level.

But, I am talking about here I am talking about movements that are performed at a smaller time scale right, it is not so, several and people who have lesions of the cerebellum, so typical inability to properly time and sequence movements, so that also tells us that you know cerebellum probably participates, and contributes in anticipation of movements or and proper muscle encoding of these moments that are required.

Then the third is a controversial claim that the cerebellum has internal models and putting it in quotes for this. So, in the some sense, at least the following is known that when you are making a movement, the limb structure and the dynamics, the mechanics associated with the movement must be properly accounted for to ensure that the movements are smooth. And it is now well known and well accepted that humans are extremely good, extraordinarily good at performing smooth movements, how do we do this?

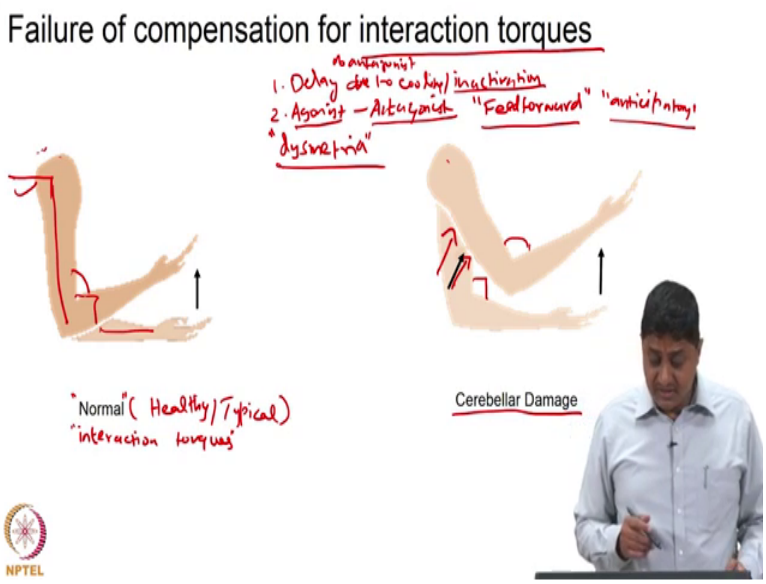
To that extent it is now posited, at least it is believed by at least some of the scientists that the cerebellum has internal models. These are models that can do one of the two, one of the following two things. I will just name these, these can be either forward models or inverse models. Now, these internal models can either be forward models or inverse models. Now, what do I mean by that.

Let us in kinematics, the following is known that if I know the end point that needs to be reached in the multi-link chain, if you know the end point to be reached, then computation of individual joint angles in that multi link chain is called as a inverse problem of dynamics or the inverse problem of kinematics right. So, I know the end point. Suppose, I have to reach that end point, I have multiple effectors right multiple links with varying ranges of movements right, I can do that, I can I also have moments at the shoulder.

So, when I have to reach that point, what could be the joint angles that would or the set of all joint angles that would help me to reach that point right that is the inverse problem; or if I know the configuration of the chain or if I know the individual joint angles, I would like to know what is the end point that could be reached.

If I know the individual joint angles, I should also know the link length. Suppose, I know both, then I could not predict what would be the end point that would be reached that is the forward model right. So, it turns out that the cerebellum implements these are the internal models in some sense or it is believed that these internal models are implemented in the cerebellum to account for the dynamics.

(Refer Slide Time: 13:55)



For example right, if I am making a movement, here is an example that is shown of a person trying to make movement of the forearm, so that is the forearm, I am trying to make that moment in healthy individuals right. When they make movement of the forearm, the shoulder does not move. Why? This is because it turns out that in healthy individuals normal as in healthy or typical individuals right. It turns out that these individuals account for what are called as interaction torques.

So, when I move a more distal part of the body, it also causes movements of the more proximal region. For example, when I moving the forearm, the movement generated by the forearm also produces and intended torques or unwanted or at least interaction torques, because this is connected to the proximal part of the body, this is connected to the upper arm. Because of that reason, it produces an interaction torque on the upper arm, causing the upper arm to move, yet in healthy individuals upper arm does not move.

Why, are there is no movement at the shoulder joint. Why, because the cerebellum anticipates that this movement of the forearm could in some sense cause movement of the upper arm. And appropriately, since muscle or commands to the muscle not directly, indirectly sends commands to the muscle, so that movements that negate or muscle activity that negates movements that could be produced here or produced. So, simultaneous or properly timed sequence of movements or properly timed sequence of muscle contractions are produced at the shoulder joint to prevent any unwanted movements that could happen. This is happening in the healthy people.

But, when a person has cerebellar damage and the same movement is performed by this person. Usually you see there is some unwanted moment, so that means, the system is not able to account for the possible effects of dynamics for the possible interaction torques right. So, the there is this failure to compensate for interaction toques.

So, also we said that the cerebellum anticipates moment. Suppose, what happens, if this ability is compromised, this has been tested in animal models by cooling of the deep cerebellar nuclei or which is a temporary perturbation. When that happens, what is observed is that there is a delay due to basically due to cooling or inactivation of neurons and the deep nuclei.

Why does this happen? So delay of what delay of antogonist moments or delay of the onset of moments, so what happens is we know that in healthy individuals to perform fast reaching actions. We discussed early, and that there is going to be tri-phasic EMG pattern, so that means, agonist moments followed by antagonist moment. For you to come to a smooth stop, the antagonist activity must start relatively early in the movement, so that you are able to stop at the point where you want to stop and in a smooth manner.

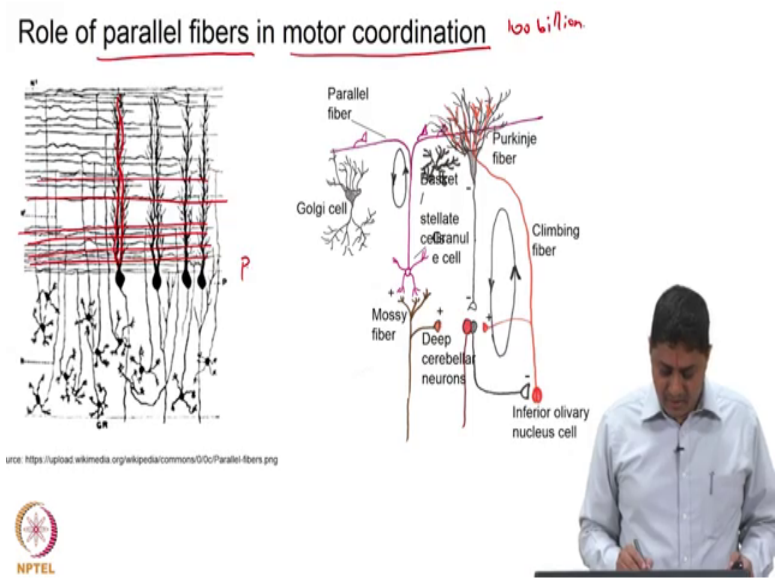
So, when I am performing that; when I am performing the extension moment right, so when I am performing that moment, so the extensor in this case is the triceps. But, for me to come to a stop at the point where I want to come to a stop suppose that is with the point, where I want to come to a stop there. If I want to come to a stop, appropriately timed activity of the biceps is required. So, I can stop smoothly right. Now, that requires sequencing of these two activities that require timing of these two activities. In healthy individuals and in healthy animals, this is relatively normal and people are able to and people and these animals are actually able to properly time these two thing.

So, agonist activity, which is followed by antagonist activity and this antagonist activity starts early on in the movement, so that moment comes to a relatively smooth stop, and that is also relatively accurate. So, this is in the some form of feed forward or anticipatory control right, anticipatory modulation. Why? I only want to stop the movement. When I want to stop, in that sense why do I have to activate the antagonist so early in the moment, actually it starts at about 20 30 percent into the movement cycle right, not on the second half of the moment. So that means, I am expecting, I am anticipating that I will have to stop at a particular point, and appropriately timing the activation of the antagonist. This is this is found in intact healthy typical individuals right.

When you cool the deep cerebellar nuclear, when you inactivate temporarily the deep cerebellar nuclei, this ability is compromised. Then what happens is that people slow down, one is that there is slowness of both agonist and antagonist. But, also this ability this feed forward feature of this movement is compromised to such an extent that the only control are the only modulation that happens is purely feedback, then the then the moment is dysmetric. So, the moment resembles dysmetria, there is an over shoot.

Are the antagonist activity does not start early enough that or it starts so late that it cannot stop the moment until after there is an overshoot. This is typical of cerebellar damage dysmetria. There is either an undershoot or an overshoot in dysmetria, but this is a classical case. Typical case of cerebellar damage, when the person is not able to meet a dark there overshooting dysmetria right, so that shows once again the important role or the crucial role of cerebellum in regulating feed forward or anticipate reactions right.

(Refer Slide Time: 21:01)

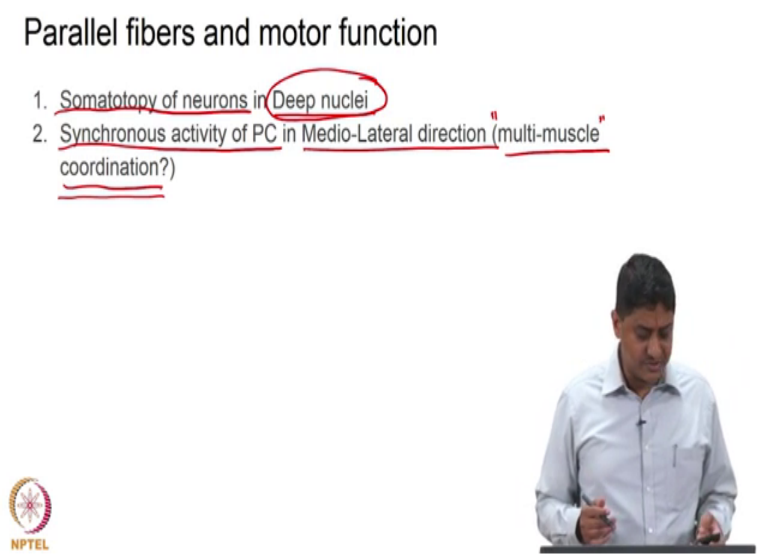


Now, we will proceed to discuss the possible role of parallel fibers in motor coordination. What could be the role of parallel fibers? We have 100 billion of these what could be the role, it turns out that recording from Purkinje cells during action, during activity in live behaving animals. And by selective cooling by selectively perturbing the system has started as a few lessons about what could be the possible role of these systems.

It turns out we discussed this earlier in one of the previous classes, we have discussed that the Purkinje system is thick in the anterior posterior direction, and very thin in the medio lateral direction. I said that you know suppose, this is the paper, it is going to be thin in this direction, but you know you are going to see a breath in that direction, we saw that in one of the previous classes. And it turns out that the parallel fibers run perpendicular to the Purkinje fibers is it not Purkinje cells that is what you are seeing here.

So, here is the tree this is a 2D structure in this so, the third dimension is not shown. So, this is the Purkinje cells dendritic tree. And what you are seeing here are all the parallel fibers. So, what has been shown is that there is synchronous activity of Purkinje cells.

(Refer Slide Time: 22:49)



So, there is also we have also discussed that there is somatotopy of neurons in the deep nuclei, I mentioned that that there is a hormone coalesce, there is upside down and turn sideways. We discussed that that or in other words, the anterior side is the tail or on the posterior side is the head right, we discussed this.

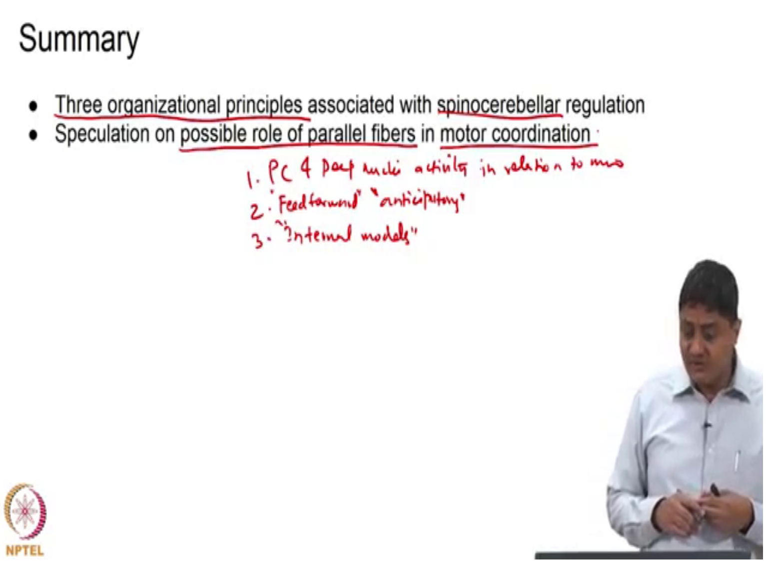
And also there is synchronicity of activity of the Purkinje cells in the Medio-Lateral direction, so that means what that means, in the Medio-Lateral direction, there are there is representation for different muscles. This representation is there, not in the cerebellar cortex, not in the molecular layer, but in the deep nuclei. And they project somatotopically, so they receive information from the Purkinje system somatotopically, this is what we have said.

So there is topographic representation in the deep nuclei. So, when Purkinje cells at are active synchronously in the Medio-Lateral direction that probably means, there is an attempt to coordinate muscles at multiple levels. And this is true, this is what we just discussed in the previous slide right.

So, here what is happening is that, this movement or change in this joint angle from about 90 degrees to an acute angle is due to different muscles is due to biceps and triceps, whereas that movement of the shoulder is due to different muscles right. Here we do not want this movement, so there is coordinated timed activity of these muscles in healthy individuals.

So, there only this joint angle change is visible is manifest. Whereas, any other there is a absolutely no change in the shoulder joint angle in that joint angle right that remains practically the same between the two configurations right, so that remains the same in both the configurations that is what is shown right. That is in the healthy individuals, so that means, that probably the parallel fibers activate Purkinje cells in such a way that there is synchronous activity of Purkinje cells or there is appropriately timed activity of Purkinje cells that leads to multi muscle coordination right. And this is critical for movement control and moment modulation.

(Refer Slide Time: 25:19)



So, what we have seen in today's class is that there are three organizational principles associated with the regulation of moments by spinocerebellum. And what are these? These are, what are these? These are that there is Purkinje cell, and deep nuclei activity in relation to movements movement. And there is anticipatory or feed forward anticipatory activity in the cerebellum. And then probably and more controversially there is this so called internal models that probably encode dynamics believed to encode dynamics of movements.

And we also discussed what could be the possible role of parallel fibers. The parallel fibers sync synchronously activate Purkinje cells at multiple regions resulting to multi muscle coordination or motor coordination. So, this is a crucial function of the cerebellum. So, cerebellum does not control movements, but rather regulates, modulates, coordinates movements, which is critical for everyday function. So, we will continue this discussion in the next class. So far now, we will stop.

Thank you very much.