Cognition and its Computation
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Lecture - 23
Motor Circuits - Sensory-motor

Welcome. We have been discussing about the sensory circuits which serve as the input to our nervous system, and provides the connection with the external world in terms of what information comes in based on which the percept forms and based on which decisions are made and so on.

And now, we will discuss the Motor Circuits which is sort of the output system if you will, that is the motor system implies the or controls the behavioral output that connects us with the external world. So, be it communication by speech, I mean we can consider it as like motor output based on which we make vocalizations and produce, or be it movement by hand to write something that we learn and so on.

So, the motor system relies on inputs from many different regions. And if you think of a particular motor movement let us say, that we know requires either it is based on memory based learning and then we execute that sequence of actions, or it can be sometime's a reflex kind of action.

So, we will not be going into much of the details of the reflex actions. But you must remember that there are numerous number of motor sequences or motor actions that we have learnt over our lifetime. And some, actually we have even forgotten that we have learnt it, it is it has become so inherent in us, like riding a bicycle or something like that. And we are always constantly learning new movements and sequences depending on the context, depending on how we have to interact with the environment.

So, there are many many many actions that are already encoded in a form based on our learned learning from childhood, like writing and so on. So, the motor system relies on the spinal cord heavily in terms of input to the motor system as well as in effective movement through our muscles. So, the main the top level control of the motor system comes from the motor cortex. The motor cortex sits right in anterior to the central sulcus.

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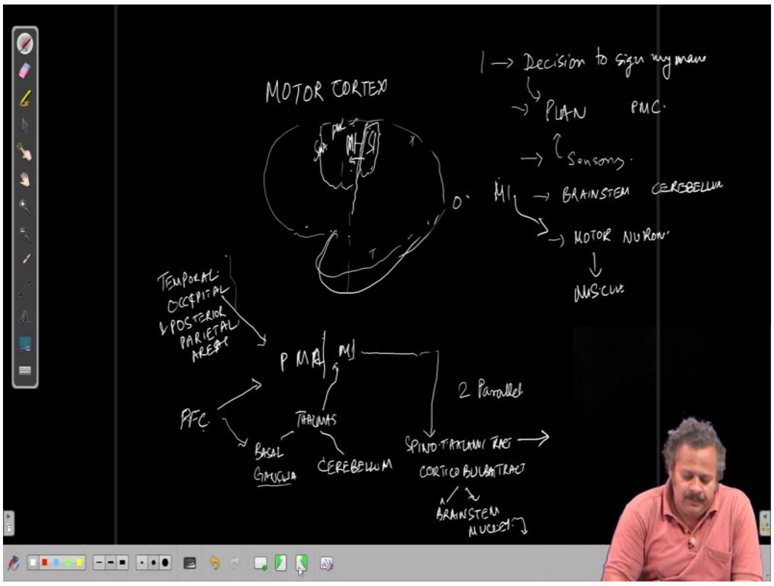

So, if you remember, if we can draw the simplistic structure of the brain like this the occipital region here, the temporal region here, the parietal here. The motor cortex lies right anterior to the central sulcus with the primary motor cortex M 1 at the first stage then it is the premotor cortex and the supplementary motor area, supplementary motor area and premotor cortex.

So, these 3 structures are at for the top level control of any movement. And the movements are executed through outputs to the spinal motor neurons, which are controlled by the motor cortex and which then project on to muscles to control their contraction and expansion.

So, if you think of one particular movement or one particular action, let us say I want to sign my name on this board. So, the first thing that comes into play is a decision to sign my name. And so that is like, that is like to decide that this is the action that I want to produce, and so that provides the initial signal and provides gating of the initiation through the basal ganglia.

Then, we need to make a clear plan of doing the signing action which is done by the premotor cortex. And then, one has to make the plan based on where the pen is, which pen to pick, where to sign, and all these have to be coordinated and in planned in a particular way.

So, all that is done by the premotor cortex and then those information is coming in through the sensory regions that we talk about into the premotor cortex. Similarly, the decision of signing the name goes into the premotor cortex via the basal ganglia and also directly from the frontal cortex.

Now, in the execution, it is controlled by the brain stem the stability of the movements is controlled by the brain stem and cerebellum, and the final execution is done by the motor neurons projecting onto muscles. And these get the signals from the primary motor cortex M 1.

So, this is in the in this whole picture, we can clearly see there are already two directions, that is the ascending and the descending systems in the motor system. As you can see that the motor system does not really get too much of direct input from the periphery like in the sensory systems.

So, the motor cortex primarily gets input from the frontal cortex or the prefrontal cortex which provides decision, the basal ganglia and the cerebellum project via the thalamus of the motor system, particular thalamic nuclei into M 1 or primary motor cortex. So, this I can actually separate this also as the premotor area or the premotor cortex. This also gets input from the temporal, occipital and posterior parietal areas. So, I would ask request you to remind yourself what these are and just going over it.

Primarily it is the sensory and association areas providing some percept of the sensory world into the premotor areas. PFC providing the decision making related signals into the premotor area. Also, this projects to the basal ganglia thalamus, so there is a loop from the frontal cortex to the basal of ganglia thalamus into the primary motor cortex.

The cerebellum on the other hand also projects to the thalamus and involved in coordination of fine movement and postural stability. The basal ganglia is involved in learning of movement, sequence of movements, cerebellum is also involved in learning of multi joint movements especially.

And finally, the descending system from the premotor as well as the primary motor cortex M 1 goes through two parallel tracts, corticospinal tract. And also, the corticobulbar tract which projects into the brain stem nuclei, which also do provide stability and postural control into the, and goes into and projects into the spinal cord to by controlling the motor neurons.

So, these this is a direct influence on to the executing motion and that is the muscles are directly controlled by the M 1 through these tract. And the corticobulbar tract is more like fine control and stability that is processed. So, in these two structures, these two ascending and descending structures the most important thing is about the coordination and or and planning. So, if you think of let us say there is a glass of water as it appears on the on a table and we want to pick it up, if you think about it in detail, there are a lot of steps that are involved.

And so first we have to gauge the distance of the glass of water, we have to plan the direction of motion, so that we are not hindered by anything in the way. And we need to move the arm in a particular direction and then grasp the water with grasp the glass of water with the appropriate amount of force, so that it does not slip or we do not crush the glass or we do not hold it too tight.

So, all this goes on through a continuous feedback sensory feedback and input control to our muscles that is adaptively changing throughout the pathway starting from an initial plan provided by the premotor cortex. So, it is an intricate process and requires number of different neurons or types of neurons to be involved in planning this execution of motion. So, the requirement here is that the continuous feedback from muscles is required.

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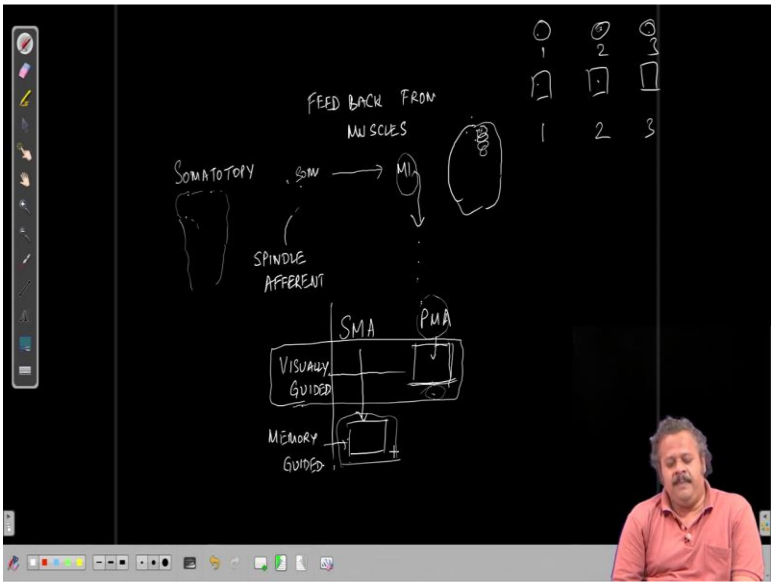

And if you recollect from our somatosensory lectures, we had talked about the spindle afferents, which provide which provide the length of the muscle, the velocity of the muscle or force generated by the muscle though that kind of information is provided into the central nervous system up to the somatosensory cortex or different areas of the somatosensory cortex.

And so there is a heavy projection to between M 1 and somatosensory cortex, which has to do with this feedback of our joints how far the joints have moved and so on. The length of the muscle, the velocity at which the muscle is going and the force that is exerted on the muscle so, all that information comes in through the somatosensory system directly goes on to M 1 and based on this, then again M 1 recalculates and provides the required input.

And in all this the brain stem and the cerebellum provide the structural or the postural stability throughout. So, in that sense, if you remember that somatosensory cortex is organized with somatotopy. So, if that is different regions of our body or the skin surface is represented by the activity of neurons along the somatosensory cortex, which lies just behind the just behind the central sulcus.

So, S 1 is right behind the central sulcus here. So, and this information goes into M 1. So, in the M 1, there is also a similar arrangement of neurons. So, this is studied through stimulation of M 1 regions. So, if we stimulate anywhere in the cortex with high enough currents, we will evoke some movement in the body. However, the primary motor cortex region is the only region that with very small current stimulation can evoke fine movements in different parts of the body.

And that arrangement of the different parts of the body or essentially the muscles that are involved to move those parts of the body is studied through such stimulation of the motor cortex regions. And we find that the different regions of the motor cortex M 1, if we stimulate one particular region, we may be moving one of the d digit d 1, neighboring region light stimulation would move digit d 2, similarly they are mapped throughout the motor cortex based on specific regions of the body.

And so there is again like somatotopy a map of the entire body on the primary motor cortex. And we can understand the effect of stimulation or activity in the neurons by observing the muscle movements at the different parts of the body. And so, the more the projections on to a particular region of the body, especially let us say the palms and the hands, and even the lips, and the oral cavity because of our chewing and so on.

So, which are heavily involved in our movements, those regions are expanded in the motor cortex because they require much more finer control like our fingers and so on. Similarly, the somatotopy is also more or less similar in that sense and we can construct a corresponding human body that is that different parts of the body is represented by the amount of real estate in the motor cortex that is engaged in controlling movement of that part of the body. And that is called the homunculus.

And you will find that the arms of that such a person you will have a picture in your reading materials would be as large as almost the entire trunk, because we rarely move the trunk, but we move a lot of features in our hands. So, now, in terms of the movements there are usually two types of movements that are involved. And these two types of movements are controlled by the or planned by the SMA, the supplementary motor area or the premotor area.

So, depending on the kind of movement that is either it is visually guided or if it is memory guided. So, what we find is that visually guided movements are primarily controlled by the premotor area and less, so by the SMA. And memory guided movements are primarily controlled by the supplementary motor area.

So, these we know from lesion studies in monkeys that if the premotor area is lesioned or damaged by some electrical stimulation, electrical lesion, or reversibly with optogenetics that we have talked about or with pharmacology in a with a inhibition agonist. Then, we find that trained monkeys who are trained to move based move their fingers based on visual guidance fail to do so. And similarly, patients with strokes in that area are not able to do a visually guided movement; that is, that requires continuous feedback and making the plan and change of action in the sequence of actions.

A memory guided movement on the other hand is unaltered by lesions in the premotor area. So, what we mean by memory guided movement is that something that has been learnt and that is not, that does not require immediate visual or other guidance to plan the action. So, let us say we are trained to press a sequence of buttons that are there, 1, 2 and 3. And let us say we memorize that we are supposed to press 1 first, then 3 and then 2, and continue this sequence 1, 3, 2. So, that is a memory guided movement.

On the other hand, if depending, so let us say now there is an LED or light at top of each of the buttons, and we have to press the button based on which light is coming on. So, if sometimes light 2 comes on, we have to press 2; sometimes light 1 comes on, we have to press button 1 and so on.

So, that is a visually guided movement, which we talked about requires the feedback and planning based on visual guidance. And the memory guided is that nothing other no other cues are present. We only know the sequence to be 1, 3, 2 and we do not need any feedback. So, it is totally based on memory and that is what is controlled by the SMA.

So, this is a very simple example. And you can easily think of many such scenarios that you encounter in real life, and you rarely imagine that we are doing a planning for that movement or we are based on the feedback that we are receiving or the memory is kicking in to tell us that this is what we should do as the sequence of actions.

So, it is such a seamless system that we do not even realize all these factors that are continuously going on behind all the sequence of actions that we take and perform, based on decisions that we take on the fly, based on the context, based on the situation, based on demands that we are faced with.

So, we will not talk about the details of the affection or the way in which the muscles are controlled. We will think of the primary motor cortex as the center that receives the perception based inputs, the decision or executive bodies inputs, and then executes a movement.

So, for learning, for getting into the further details of this we will have to consider something that is called the sensory motor system and later on also the executive circuits. So, the sensory motor system is essentially what we briefly talked about, is the system that provides the sensory inputs to the motor cortex to affect the behavior.

And in the executive circuits we will be talking about how what executive circuits finally, signal to the motor cortex or for a particular behavior that needs to be executed based on the context and demands of the situation. So, with this, we will conclude our lecture on the Motor Circuits. And we will take up the Sensory Motor Circuits in the next lecture.

Thank you.