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

Lecture-70
Basal Ganglia Motor Functions

Welcome to this class on Neuroscience of Human Movement. So, in this class we will continue our discussion on basal ganglia and motor functions of the basal ganglia.

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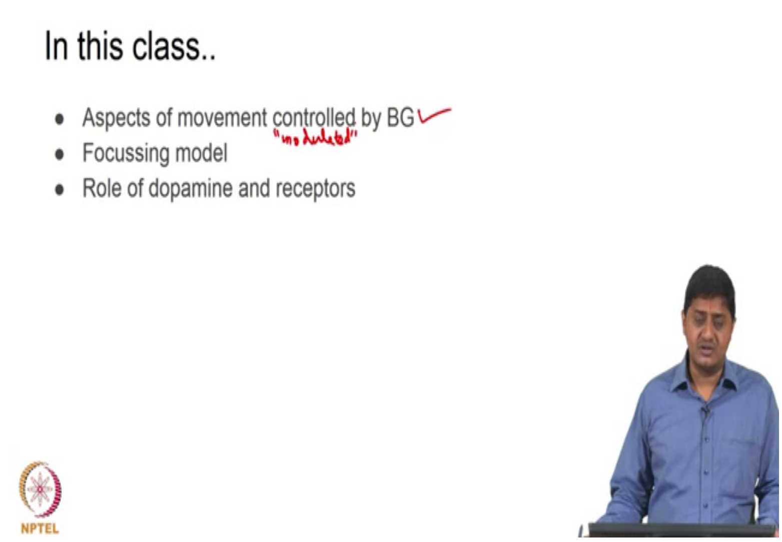

In this class, we will specifically focus on aspects of movement controlled by the basal ganglia what is known is that basal ganglia contributes to motor related function in animals and humans. But what aspects of this movement are controlled are modulated by the, specifically we will focus our attention to what is called as the focusing model of basal ganglia function. We will discuss how well this represents the actual reality, actual and we will also discuss the role of dopamine and its receptors.

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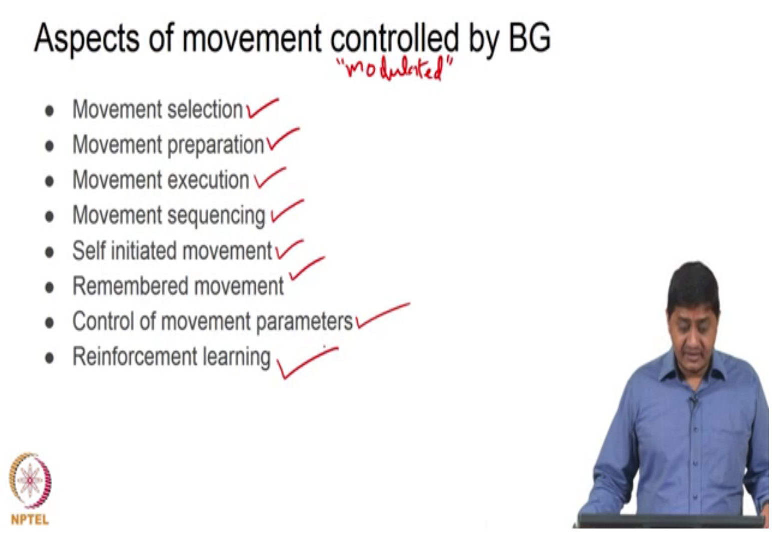

Essentially the following different aspects of movements have been. So, essentially it has been observed that the following aspects of movement are modulated by basal ganglia for want of a better word controlled may be considered as a strong word by some of us one using a different, but modulated by basal ganglia. Selection of specific movements, preparation before the movement, preparation to an action and execution and sequencing which one to do first which one to do next and why. And remembered are self initiated movements or volitional self initiated remembered control of specific movement related parameters such as displacement and velocity such as force and rate of force development for example.

And reward related behaviour are reinforcement learning. So, essentially these are believed to be the various things that can be modulated by basal ganglia and you realize practically that is almost all the things related to movement related functions. So that means, basal ganglia is an important part of the motor loop and its function are healthy function of basal ganglia is essential for healthy movements right. So, a lot of information about basal ganglia function has come from motor disorders, the idea that basal ganglia participates in movement selection essentially comes from the observation of movement disorders that arise due to disfunction of basal ganglia. So, a lot of this comes from basal ganglia disfunction related data, but there is there are also other ways of studying this which we will discuss in this class.

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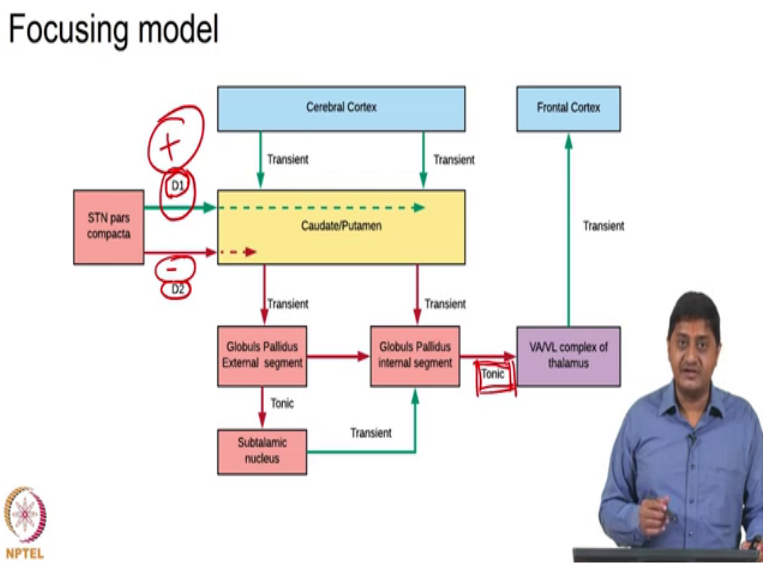

So, essentially the notion, the idea that basal ganglia participates in movement selection may. So, whenever you say selection what you are implying is you are going to select something that is beneficial to you now; that means, you have to know what is beneficial right. So, you have to have a value function. So you must know what is the value of something and if the cost of doing something is worth the value that is going to be received in some abstract sense right so, I am going to make a movement is it worth to make that movement for example.

I am going to do something I am going to say for example, write an exam is it worth writing that exam will I pass or what is the use of writing the exam if I pass even if pass will I am going to get something out of that for example. That is planning for an action, planning for some event right here we are talking about the role of basal ganglia in movements selection. Should I make that movement or say this movement say there are two choices, say there are multiple choices in life we have multiple choices to make by the way not making a choice is a choice is important to note.

If I am not voting, NOTA is considered a vote, right. You go to the polling booth to say NOTA. Not making a choice is a choice, but other than that we have several life choices to make. In particular within movements also there are several chances to make. Should I move to this target or that target? Should I take this route or that route? There is oil spilled on the floor, should I cross the oil, can I jump over it or should I take a different path? Decision making essentially I am selecting something.

So, that has to be done in a way that is beneficial to me, right. It is highly unlikely for you to make a decision that is detrimental to your health, right. Nobody make such decisions. So, except of course if you have a disease; if you have a disease you will make decisions that is detrimental to your own well being, but other than that no healthy person would actually make a decision that hurts themselves, right. So, that means what is essentially happening is not just movement selection, but also some form of reward related evaluation. So, I am comparing and outcome are a possible outcome or an expected outcome with the cost that is involved in performing the movement. If I do this, if I do if I make movement A, if I reach target A, what am I going to get? If I reach target B, what am I going to get?

Which is going to be more beneficial and what is the cost involved in making this movement verses that movement? Alot of these things are probably performed by the basal ganglia. How exactly the basal ganglia perform, this continues to be a mystery. So, we do not understand that part, but it is hypothesis that this is what is being done. So, essentially when you say selection you refer to this particular feature. You mean something that is selected is essentially beneficial to the organism, right. That means, that there is reward related behaviour; that means, there is reinforcement coming in.

The idea that basal ganglia participation selection or it acts as a great to release movement has come from the observation that the output nuclei of the basal ganglia continuously or tonically inhibit the thalamo cortical neurons. This is something that we have discussed in the previous classes. The output of the basal ganglia is essentially inhibitory. So, the globuls pallidus internal is continuously inhibiting the thalamo cortical neurones transient release from inhibition of these neurons are this inhibition of the thalamo cortical neurones essentially produce movements. So, that is like a gate. So, there are several people waiting say in this room or in some room, 1000s of people are waiting and there is a small gate like in a movie theatre for example, right. There is a queue to enter, right. There is a gate that the person opens for you to go in. Not everybody can go. So, there is gate.

So, the idea that there is a gate or the basal ganglia acts as the gate and selection actually comes from the major output nuclei tonically inhibiting the thalamo cortical neurons. Important to note is the role of dopamine in this, right. It turns out that dopamine excites the neurones in the direct pathway and inhibits the neurones in the indirect pathway. But since, the direct pathway essentially has and excitatory influence on the thalamo cortical neurones and the indirect pathway essentially has an inhibitory influence on the thalamo cortical neurons. Please let us remember this the direct pathway essentially has an excitatory influence on the thalamo cortical neurones.

So, when the direct pathway is activated, the thalamo cortical neurones are going to be excited or more excited, right. When the indirect pathway is activated, the thalamo cortical neurones are going to be more inhibitor, right. Important to note is the function of substantia nigra pars compacta in this, right. What substantia nigra pars compacta does are is basically has the nigrostriatal neurons that release dopamine. What dopamine does is different on the different pathways are very important principle to remember. Students of this course must remember these principles core concept right that dopamine essentially excites the direct pathway and inhibits the indirect pathway. So, that means dopamine essentially has a net excitatory influence on the thalamo cortical neurones. Why is that? Because let us remember one more time the direct pathways is excitatory and dopamine excites the excitatory redirect pathway. So, that means what? That means a thermo cortical neurones are going to be excited, right.

The indirect pathway is inhibitory, but dopamine does not excite the indirect pathway, but rather inhibits the indirect pathway. That means, it reduces the effect of the inhibitory indirect pathway or in other words, essentially it reduces the net inhibition provided by the pallidal neuron to the thalamo cortical neurons. That means, essentially is increasing the excitability of the thalamo cortical neurons even in the indirect pathway. So, essentially the net effect of dopamine on the thalamo cortical neurons is always excitatory that is because there is the presence of two different receptors; D1 receptors are present in the direct pathway and D2 receptors are present on the medium spiny neurons of the indirect pathway. The D1 receptors cause an excitatory postsynaptic potential in the medium spiny neutrons right and the D2 receptor cause an inhibitory poor synaptic potential in the medium spiny neurones, essentially having different outputs, right essentially having a having differential output. That means that the net output at the thalamo cortical level is always excitatory.

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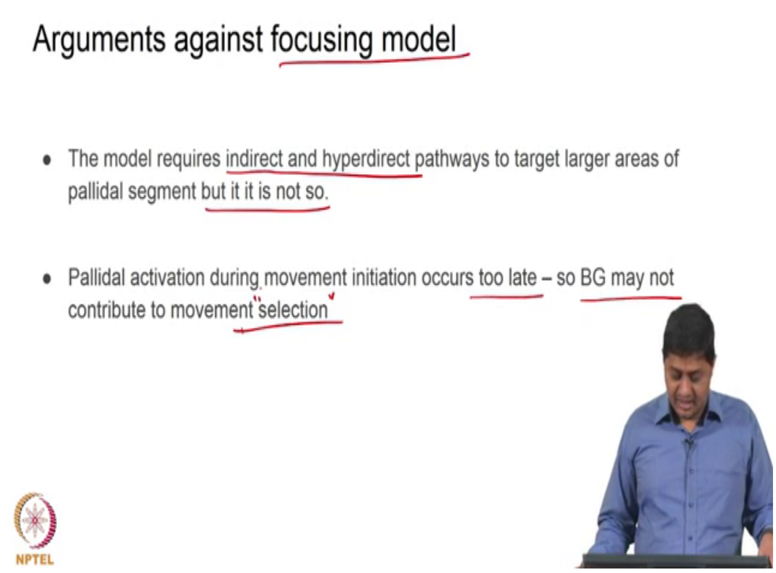

So, that means essentially what the basal ganglia does is focusing, right. So, basically it is selecting one movement in set of movements is the impression that we would get. So, like it happens in perception for example, right. So, essentially this is what the focusing model would have us believe that there are lots of movements and many of those are unwanted. They are all inhibited the wanted movement alone is led out like the gate.

But what happens what is the anatomical requirement for this to happen, but it requires is that indirect and hyper direct pathways should target a relatively larger area of the pallidal segment, whereas the direct pathway should focus on the specific area of the pallidal segment. This is what is focusing, right. Essentially indirect pathway inhibits broadly a large area of the pallidal segment and the substantia nigra pars reticulata the output nuclei are inhibited broadly a specific movement that needs to be performed or the specific circuit that needs to be used alone is activated that is focussing, right.

So, is that really happening anatomically? So, does the indirect pathway target a large area, whereas the direct pathway target a relatively smaller area? The answer is no. It turns out anatomically this is not so. So, that means our understanding using the focusing model is limited. It is a nice model, but they only provide so much information it is a speculative model, right. Then also another requirement pallidal activation during movement initiation actually occurs a little too late. So, it might be too early for us to conclude that basal ganglia participates in movement selection per se, but in some cases at least in some cases, pallidal activation occurs a little too late.

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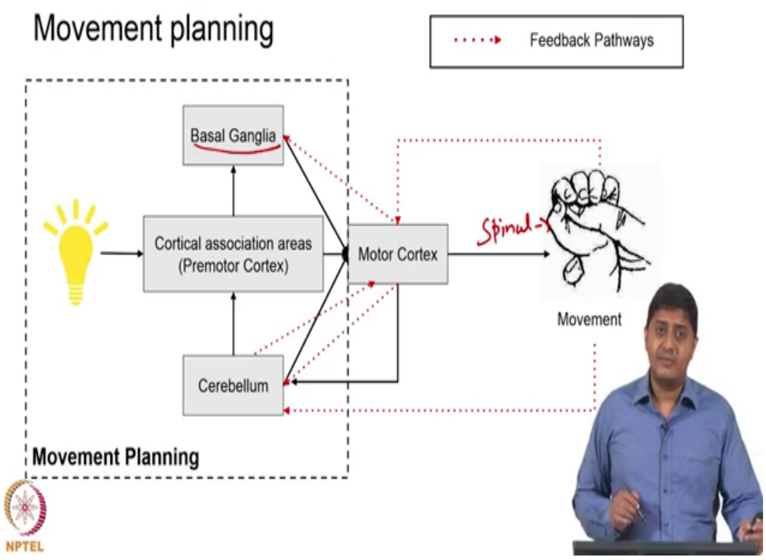

And again let us remember that how movements are planned, right. So, essentially movements are performed through spinal cord activation of specific muscles and that comes from the that receives input from the motor cortex and brain some areas, right and motor cortex interacts with basal ganglia and cerebellum. Essentially basal ganglia is participating as a modulatory or influences the movements right something to remember.

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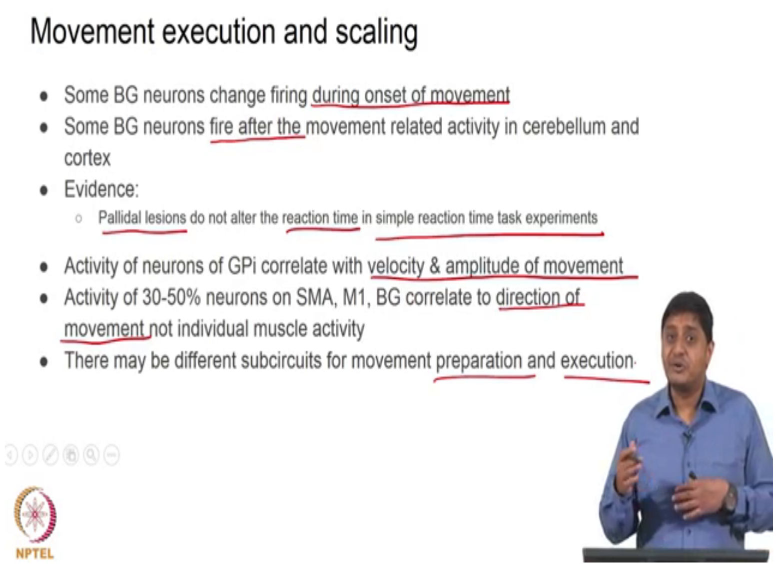

Some basal ganglia neurons change firing during onset of movement, whereas some other basal ganglia neurons fire after the movement related activity. So, in the cerebellum and cortex, so it is not that all basal ganglia neurones perform essentially the same function. This does not seem to be the case, right. In particular pallidal lesions do not alter the reaction time in simple reaction time task experiments, right. So, press when the stimulus is coming not when there are two choices, there is only one choice and I am just pressing whenever say a stimulus is presented, whenever the stimulus is present, just press the button right.

When this is performed on an animal that has a pallidal lesion, there is no change between the simple reaction time. When the animal has pallidal, there is intact and when there is lesions in the palladium regardless of this the simple reaction time actually remains the same. So, it is very important to note.

Now, so activity of neurones in the globuls pallidus internal segment correlate with specific aspects of kinematics right, velocity and amplitude of the movement now also about 30 to 50 percent of the neurons in supplement motor area are primary motor cortex and basal ganglia correlate with the direction of the movement, with the direction of the movement, but not to individual muscle activity. This is something that we mention in the previous class. So, essentially when there are multiple targets if I have to move to particular target, right that is encoded in specific neurones, but not which limb is moving or which muscle is moving.

So, essentially it seems like basal ganglia is operating in the space of the target or in the space of the destination of movement, but not in the space of muscles. So, essentially what basal ganglia probably encodes is a decision to move, right. So, in that sense basal ganglia forms a part of the decision making loop. So, that means that it gives some point as to what the basal ganglia might be doing in the executive decision making loop also. Here we are studying motor function, but probably we can speculate about the role of basal ganglia an executive decision making, right.

Again there may be different circuits for movement preparation in execution. So, one is selection, then there is preparation in execution it turns out that it is probable that there are different sub circuit for preparation and execution.

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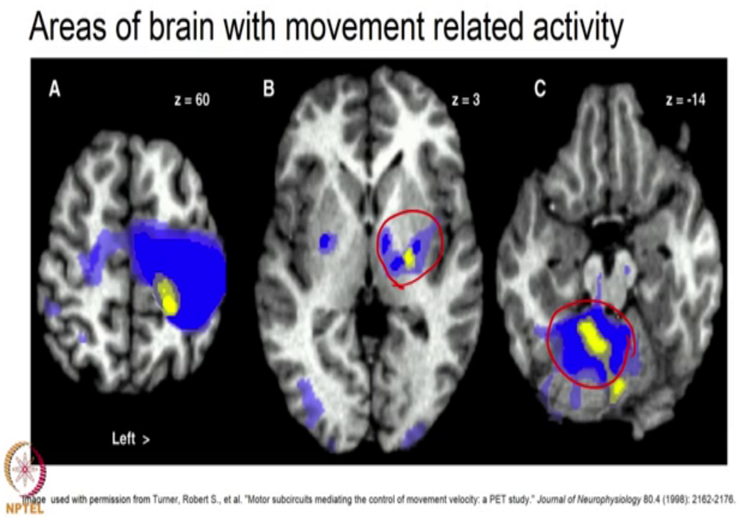

So, here we have a picture showing movement related activity. So, this is PET scan put on top of an fMRI image to highlight which particular areas of the brain are active during which particular movement, right. Movement related activity in the basal ganglia on thalamus are actually seen or actually found in specific motor related areas of the basal ganglia on the thalamus right, primarily on the side contralateral on that is moving, right.

Note here on this side though it is on the ipsilateral side that is cerebellum on the right. Obviously, cerebellum controls ipsilateral movements are movements on the same side of the body, whereas motor cortex controls movements on the other side of the body. Basal ganglia also seem to control at least from this data in this case seems to control mainly movement on the contralateral side, but also note that there is some ipsilateral activity.

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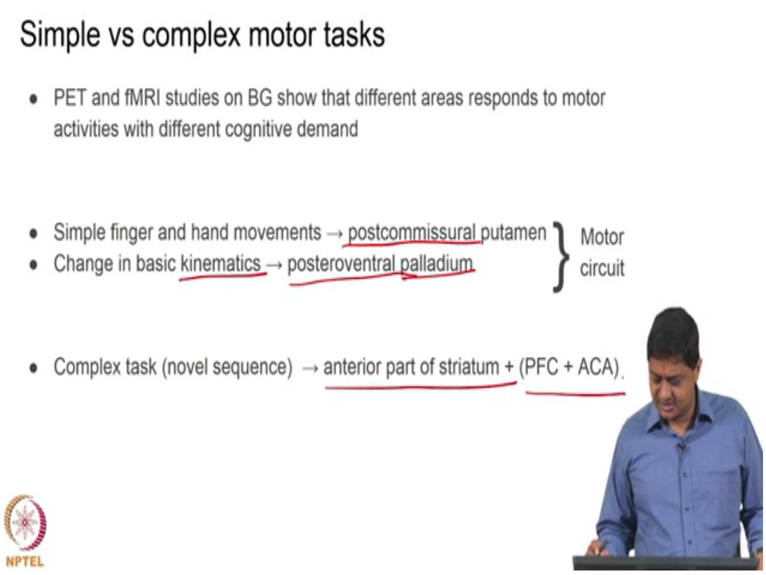

So, essentially PET and fMRI studies on basal ganglia has shown that different areas respond to motor activities with different cognitive demand. So, if it is a simple task, one area of the basal ganglia response; and if it is a relatively complicated task that involves changes in the space of operation involved in kinematic changes. Then, it turns out that at different area of the trade striatum is active. So, here this is postcommissural putamen and here this is post posteroventral palladium, right. So, again it is not essential for you to remember which area is responsible for which, but it is essential for you to remember that you know different areas for simple and complex movements are used, right. So, again complex task is used for the anterior part of this striatum with the prefrontal cortex and ACA.

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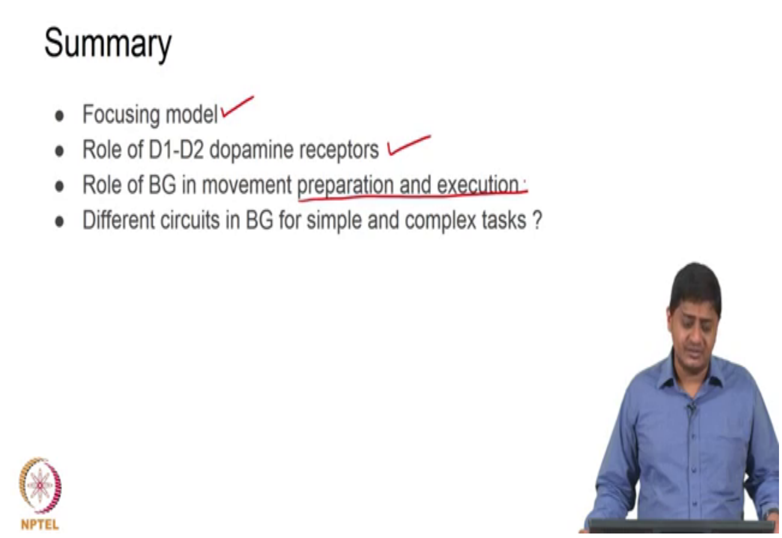

So, in summary we have discussed in some relative detail the focusing model of basal ganglia function and that different role of the D1 and D2 receptors. The D1 receptor excites the medium spiny neurons; the D2 receptors inhibit the medium spiny neurons, but the D1 receptors are essentially present in the direct pathway and D2 receptors are present in the indirect pathway. Only in a few medium spiny neurons you find both D1 and D2 receptors present. Those are exceptions. In most cases, D1 receptors are present in the medium spiny neurons on the direct pathway and D2 receptors are present in medium spiny neurons on the indirect pathway. And since the indirect pathway is an inhibitory pathway, D2 receptors inhibit the medium spiny neurones essentially producing excitation at the output. This is important excitation of the thalamo cortical neurones is produced by document.

Regardless of which particular pathway it is acting on, if dopamine is acting on the direct pathway it is going to excite the direct pathway. If dopamine is acting on the indirect pathway, it is going to inhibit the indirect pathway, but since the indirect pathway is inhibitory, you are going to have a net excitatory effect of dopamine on the thermo cortical neurones. And of course, movement preparation and execution are important functions of basal ganglia and it is possible that we have different circuits in basal ganglia for simple and complex tasks. We believe that too speculation. With this we come to the end of this lecture.

Thank you very much for your attention.