Cognition and its Computation
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Lecture - 24
Reward Circuits

Welcome. In continuation of our discussions on brain circuits, we have discussed the motor circuits, sensory motor circuits. And, now we will talk about the Reward Circuits which are extremely important in terms of learning and various cognitive aspects. So, a reward circuit or the brain parts that are involved in what we call reward is essentially things that evokes, not just things I mean it can be stimuli, it can be behavior, it can be some memory that evokes pleasure or positive balanced emotion.

And so, all these things can serve as rewards and they are linked to various aspects in our lives in terms of associative learning. Whenever we are trying to learn associated reward helps us in learning. Secondly, it is involved in motivational behavior that is providing motivation to perform a certain task, a goal directed task. And of course, thirdly it is the feeling of pleasure or liking from a particular activity or a particular task like playing a particular game or spending time with someone you like and so on.

So, when we say associative learning, it is basically that if we have to learn a particular task and it is associated with a reward. And that completion, successful completion of the task we are given a reward, that is we stimulate that part of the brain that helps us realize the positivity or the positive emotion evoking aspects of the task or the or the positive aspects seeking behavior in the task, that gets enhanced. And, we gradually know that we want to perform this particular task to get that reward.

Similarly, memories can be evoking positive balanced emotion that we want to want we derive pleasure out of and also things that evoke hedonic liking or pleasure. So, all these are orchestrated by particular circuits in the brain. And, we know from various stimulation studies that there are key elements in the circuitry in the brain, where if we stimulate the neurons there; we feel the same kind of pleasure or positive balanced motion as a reward.

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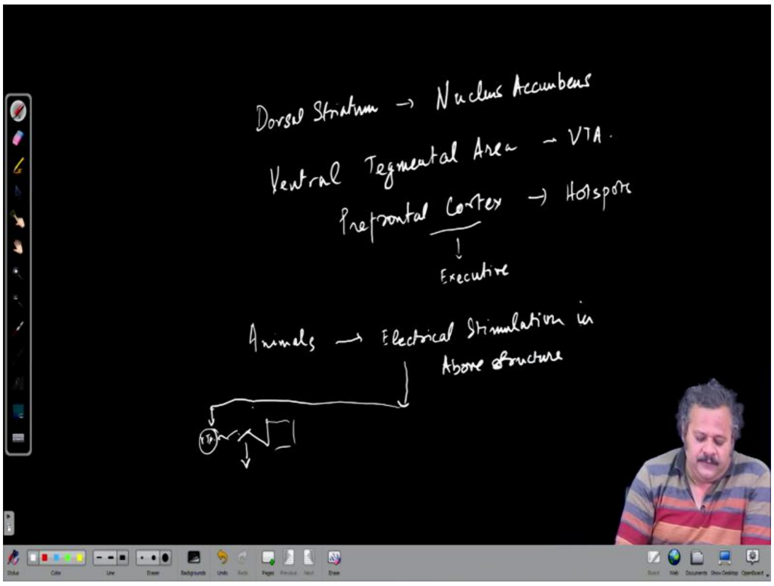

So, some of these centers are the part of the dorsal striatum or the nucleus accumbens part of it, nucleus accumbens. The Ventral Tegmental Area which is near the substantia nigra region that is involved in also motor behavior. And, this basically called VTA.

Prefrontal cortex, there are hot spots in the prefrontal cortex which is also we will be talking about this more during our executive circuits lecture. And, parts of it there are hot spots in there stimulation of those points lead to reward behavior, I mean lead to the feeling of obtaining a reward. So, in overall there are also other regions like in the hypothalamus like lateral hypothalamus that also stimulation leads to your odd behavior.

So, these particular structures are such that if animals like rodents which have been done in animal, other animal models also. If they receive a stimulation in these structures, electrical stimulation above structures then in after they complete a particular behavior or particular task. So, the animal let us say is knows that it has to press a lever with its paw.

And, if it presses the lever there is an electrical stimulation in its let us say the ventral tegmental area, in the VTA of the animal ok. Then, it continues to keep on pressing that lever. I mean it can it can even forget about food and water and anything and in fact, die or lead to that stage where it is completely exhausted. And, but it still keeps on pressing the lever.

So, that is how powerful the reward system is that we depending on how strongly we are activated by this in these circuits in the neurons in the circuits, we can keep on seeking that particular behavior that evokes activation of the neurons in the circuits. So, along with reward comes the additional drawback of over rewarding and that leads to addiction. So, an important part of cognition and studies of psychological disorders is to study addiction and that is inherently tied to the reward circuits.

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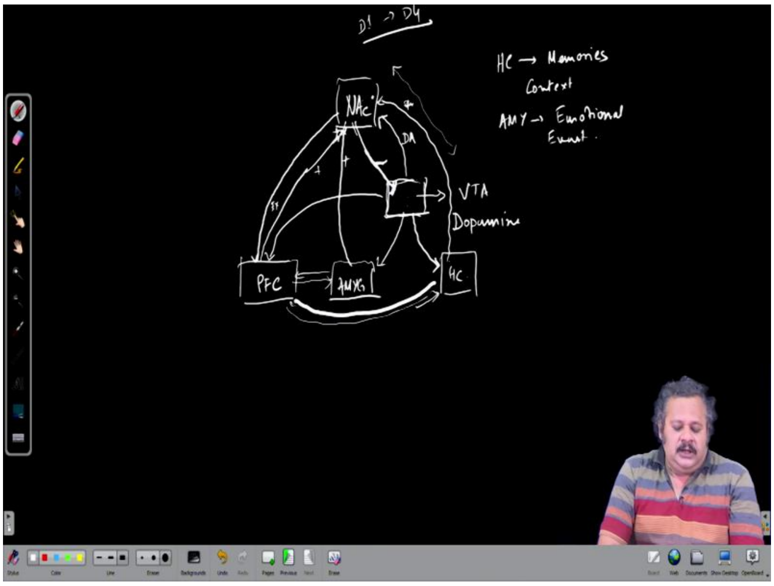

So, if we take brief look at how the circuits are engaged, then the VTA region in the ventral tegmental area; this contains dopaminergic neurons that is neurons that produce dopamine as the neurotransmitter. There are other also other regions besides the VTA like the substantia nigra pars compacta. And, other substantia nigral regions which connect to striatal circuits which are also dopaminergic and are involved in associative learning and so on.

But, particularly the VTA is important in reward in the sense that it projects to a key structure in the dorsal striatum called the nucleus accumbens, as we introduced. This is in the dorsal striatum. So, this is dopaminergic input that is dopamine is the neurotransmitter that is released in the nucleus accumbens. And, then there are D 1 to D 4 different dopaminergic receptors. Each of them having separate functions, separate functional effects on the postsynaptic neuron could be inhibition.

And so, depending on the receptor type, it could be inhibition and primarily it is inhibition and can also lead to excitation. And, there are also inputs on to the dopaminergic terminals. The axon terminals that project on to the nucleus accumbens and also other places. They also express certain receptors of another neurotransmitter acetylcholine which can modulate the release of the dopamine.

So, this these two are very important structures in terms of reward behavior. The VTA also projects to the amygdala which is part of the limbic system which you will learn about, then also hippocampus again the labeling system. And, it also projects to the prefrontal cortex: PFC. So, all these four structures are involved in this reward behavior. And, all of these are modulated by dopaminergic inputs from the ventral tegmental area which is the key point in eliciting reward driven behavior.

So, the nucleus accumbens also projects on to the PFC with excitatory inputs. And, then the PFC can also feedback into the nucleus accumbens and the nucleus accumbens through its inhibitory effect can inhibit. So, this is a minus sign, inhibit the VTA. So, there are connections between PFC and amygdala back and forth. Similarly, between hippocampus and PFC back and forth and other circuits are present.

But, it is through this inhibitory feedback on to the ventral tegmental area, that the regulation of the reward system happens; that is DA being inhibitory, they are inhibiting the medium spiny neurons in the nucleus accumbens. And, the nucleus accumbens thus those neurons are getting inhibited and they which were initially inhibiting the VTA neurons are gradually are actually removing its inhibition on to the VTA neurons, the dopaminergic neurons.

So, increase the dopaminergic input on to the nucleus accumbens. And that finally, leads to the associative learning and regulation of the reward mechanism and association of the reward with a particular behavior.

So, the nucleus acumen and VTA as we can see are highly involved in the process of regulation of the reward or finding the right associations with the cues that are provided into the VTA to associate with the reward. And the PFC finally, orchestrates that learnt behavior by driving the output behavior required for it. So, the hippocampus which also provides an input to the nucleus accumbens.

The amygdala which also provides an input to the nucleus accumbens excitatory. All these are excitatory inputs, the glutamatergic inputs. So, they are involved in this manner that hippocampus as we know has to do with contextual memories. And so, a particular context that by memory we know is rewarding that activates our nucleus accents through the inputs from the hippocampus. So, learnt associations or memories of particular events, particular stimuli that are stored they can again evoke the reward through these inputs.

Similarly, the amygdala which basically is like center for strong emotional memories or emotional events. They also provide input to the nucleus accumbens for recollections of rewarding incidents; extremely strong positive emotion based incidents. And so, they are also involved in the reward behavior, emotional events, strong emotion evoking events. And, the PFC is more involved in the learned associations and then orchestrating a behavioral output.

So, the PFC is more like with the VTA is going to drive the behavior that evokes the particular rewarding element. So, the on the other hand when we have excess of if you think of the nucleus accumbens as the element which is getting the dopaminergic inputs, that is signaling the reward. This is dopaminergic inputs, dopamine being process dopamine being transmitted on to neurotransmitter in neurons in the nucleus accumbens.

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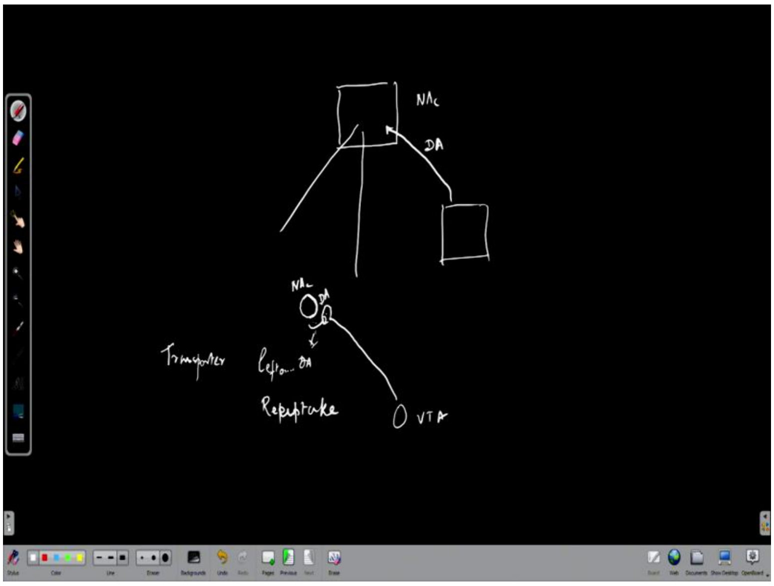

This process is what is heavily affected in addiction mechanisms. So, if you think of the neurons in the nucleus accumbens. Let us see a blow up and let us say we have a synaptic terminal which is coming from a neuron in the VTA. And, this terminal is dumping dopamine into the synaptic cleft as you know from our previous lectures on how synaptic transmission happens.

So, the dopamine not all of the dopamine gets to bind to receptors in the nucleus accumbens neurons. So, there is a left-over dopamine in these regions in the nucleus accumbens. And, the drugs of abuse or addiction primarily act through like cocaine and methamphetamine. These act through stopping or blocking of the reuptake of the dopamine back into the dopaminergic terminal.

So, there is a transporter of dopamine that takes the left-over dopamine in the synaptic cleft that is packed back into the vesicles in the dopaminergic terminals. So, the effect of addiction of drugs is such that, that the transporter is blocked by the drug. So, all the dopamine that is being released takes a much much longer time to get back in. And so, this leads to a prolonged release of dopamine much longer than that is required for a particular rewarding experience.

Instead, that keeps on dragging on to provide that additional the rush; so, to speak of the taking of the particular drug. And so, that leads to a behavior of seeking that over and over again, like what we discussed about stimulation of the reward circuit elements. Like the nucleus accumbens or the VTA as we discussed earlier on about mice or rodents pressing a paw pressing a lever with their paw.

And, the if that is connected to stimulation of these specific circuits; they keep on a stimulating, they keep on stimulating themselves via the lever press. And, that is the seeking behavior, the continuous seeking behavior which is like a positive feedback. And, that is exactly what happens when we block the dopamine reuptake into the dopamine energy terminals for the projections from VTA on to nucleus accumbens. And of course, there are many other effects of the reuptake block of reuptake of dopamine.

And so, it is not purely just that it is a that reward and reward seeking that continues. So, in the later lectures when we talk about learning, associative learning and also in memory, we will discuss about the details of this how this association actually happens through circuit elements, that or the neural action potentials with dopaminergic modulation in associative learning.

For example, the usual procedure in how we look at learning in animal models is through providing rewards for a task. And, an animal learns to learns the task because of its seeking the reward over and over again. Not in a pathological way, but in the sense that it, it is required for it the for its normal functioning. And, that is used in terms of understanding this kind of a behavior is used for understanding how we do positive reinforcement, how we at the circuit level do positive reinforcement and learn various tasks.

So, just like reward, there is the opposite of that and that is the anti-reward system which is not so well talked about or discussed or even studied so much which is actually the opposite of the reward as the name suggests. And, that also involves similar circuitry and set of different molecules that actually stop or control the reward seeking. And, those are explored for work on the rehabilitation of addiction behavior, addicted people and so on.

So, with this we will stop our discussion on the reward circuits. And, in the next lecture we will continue with discussion brief overview of the circuits involved in executive functions.

Thank you.