Animal Physiology
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Module - 1
Lecture – 18

Welcome back to the lectures in animal physiology in NPTEL. We are in section 5 and lecture 9. Today we will be discussing about the special senses; senses which are fairly advanced in human being and in other species. Some of these senses are better than human being; yet some others are lesser than human being. One the senses which we will be talking about will include hearing, which is fairly well developed in human being. There are certain other species, like dogs, and few others, which could sense vibrations at much lower frequencies, which we cannot sense.

Apart from it, we will be talking about the vision, which is very well developed in human being as compared to other species. Then we will be talking little bit about the taste and then we will talk about olfaction. In case of olfaction, in human being, it is less developed as compared to species, like rats or some other species, which depends a whole lot on olfaction. So, the logic is like this. The modality of the sense, which is used maximum by species is much better developed as compared to modalities, which are used less. In case of small rodents, like mice or rats, they need a lot of support from the olfaction, because they have to smell around and they have to reach their food or their target.

Whereas, in our situation we depend on whole lot because, we are kind of a straight, like erect. So, we have to look around. We are tall. So, we depend a whole lot on our vision and our hearing. These are much better advanced modalities as compared to olfaction. Maybe, at some point or otherwise, human being was evolving olfaction, may would have been a better modality, but currently our olfactory power is far less as compared to olfactory power of a rat or a mice, provided, our taste buds are much more fine tuned.

Let us start with kind of, getting an idea what is happening. But basic theme, what one has to, which I will be drawing anyway, realize is that these special sense organs are nothing, but very specialized neurons. These neurons have the ability to sense the specific modalities like light, frequencies or sound waves, or a particular molecule by ending with (( )) or taste buds or volatiles, in the form of nose. In the nose, the volatiles are being identified. These information are coded all along and reaches to the central nervous system. Within the central nervous system, these are being decoded because, it is something like this, say for example, someone in your childhood taught you while you are growing that this is an apple.

Now, you see an apple then that wave moves through the brain, and in the brain, this specific area which has already a stored memory of apple, it tells you to realize. So, this is an apple. Same way, you smell something, say for example, you smell h 2 s gas, which is a very awkward smell. You went to your first chemistry practical, maybe, long back in class 6 or 7. When someone taught you, that it as h 2 s gas, that olfactory memory remains somewhere, stored in your brain. The next time, when you go to a new place and you smell, that you say that is h 2 s.

So, that h 2 s is basically, you smelled a fresh h 2 s in another lab, which is in your lab. Now, that signal went from your nose, all the way to the brain, through the sensory modalities, to the sensory neurons and there, it was decoded by the brain. Because, it already has a stored piece of information, it comes up via, maybe, long term potentiation or a long term depression. It may be some totally unknown pathway. It is already known, and that signal or that stored memory helps you, to realize this is h 2 s and then you decode that piece of information. Same holds to hearing also.

You hear from your childhood; you hear the sound of your say, father, mother. So, that frequency is coded in your brain, in the hearing area. These are all coded. There are cortical zones, where the hearing information is being processed. Based on that, you make your; this is my father, who is speaking; this is my mother, over a phone. You never had to process that who is talking unless; it is some totally different voice. So, the modality remains the same. Here is the sensor; here in your eyes, in your tongue, in your ear or in your nose. Those sensors senses the signal, electrically coded the signal all the way to the brain, and in the brain; brain decode the signal based on the memory traces, which are already stored.

It is a kind of matching. Sometime, you say this smell is very similar to hydrogen sulphide smell or h 2 s smell; that means, this is not really that, but it is kind of close. In other words, the information or the electrical signal which is stored, is very similar to the electrical signal of this x y z molecule, which you say is very similar, but it is not the same. With this, let us formally draw the different structures and get into it appreciate the way, nature has designed us or evolved us, to make us more smart individuals.

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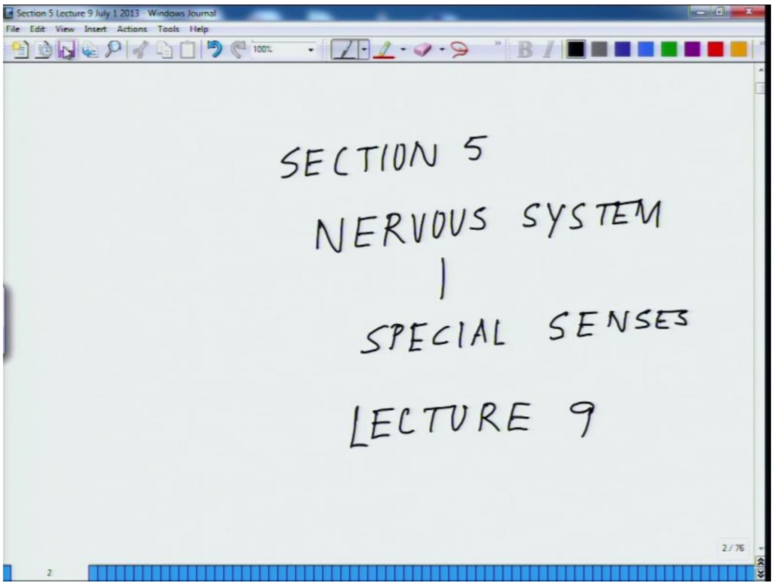

We are into section 5 in nervous system and within nervous system, now we are into special senses and we are into lecture 9.

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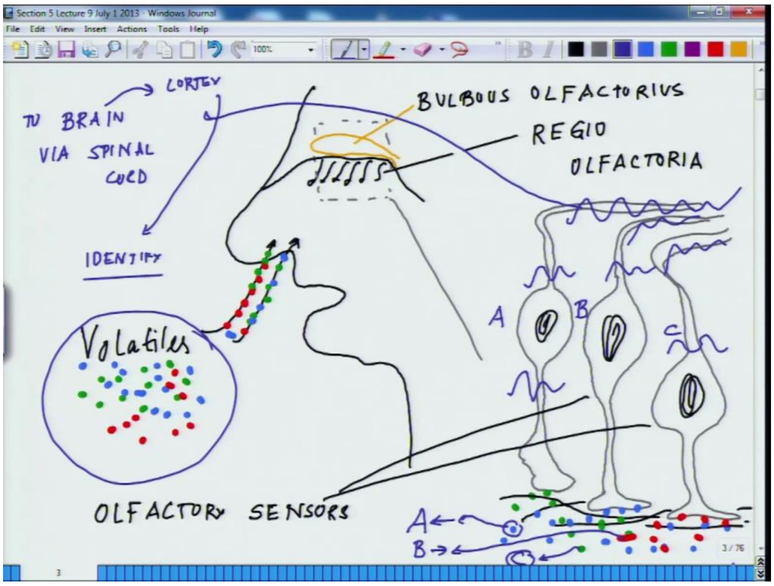

Let us first start with our olfaction, which is not very well developed. Regarding olfaction, this is the nose of an individual. What exactly is happening in the nose? These are volatiles. There could be several kinds of volatiles, which are reaching. These volatile molecules enters, let us represent the volatiles in terms of something, like this. These are different kind of volatile molecules; different colors represent different kind of volatiles. These volatiles are entering your nose. Inside the nose, what is happening is, right here, there is an area which is called region olfactoria. This is called regio olfactoria and on top of region olfactoria, is bulbous olfactorius, something like this. If you really look at the cross section of this, at the cellular details, it looks like this. So, there are individual cells like this. These are the olfactory cells, likewise. These cells, what you see, this is the zone where this is all the crisscrossing out here, and these are the nucleus of this individual sensory cells.

So, these are the sensory cells. These volatiles, what you are seeing out here, reaches here; all the different volatiles. These volatiles bind to these specific neurons, specific cellular. So, these are the sensory. What you see out here, what I have just now drawn are olfactory. You can call them olfactory sensors. What is happening is, that these specific volatiles bind to these cells, and once they bind to these cells, they generate a electrical current out here. This electrical current is all the way travelling to the spinal cord, depending on. So, either these individual cells, what you see, they bind to a specific kind of volatiles or they may be a combinatorial output.

Say for example, this one, I mean them as A, B, C. Say for example, one option is that A binds to only this blue ones; B binds to only the red ones; C binds to only the green ones. There is one option, how the electrical signal can reach, or they may be, like all them bind to all of them. But there is a different kind of coding, but most likelihood is, like this; that there are individual set of a sensors, which bind to specific volatiles and based on that, a signal is being generated out, along this pathway and it reaches to the brain.

Say for example, now you have a mixed volatile coming, which has few reds or say for example, 100 molecules of red; 20 molecules of blue and say, 10 molecules of green. So, total number of signal of the one, which is the highest, will be bound and that will create the highest amount of signal, as compared to the other one, which are 10 and 20. So, those signals will be less. Automatically, when the brain will be processing this information, brain will tell the one, which has highest number of signals, that smell is being dominated by those volatiles, which are present in higher concentration in a mixture, or you may have a pure red; all that red molecules are there, or maybe a pure green or a pure blue or anything.

So, there are 1000s and 1000s of volatiles all across the world, and based on that, they have olfactory memories, which are, I will not say well developed; it is good enough for our survival in human being, as compared to rats, mice or other rodents; which are to depend a whole lot. So, this is the basic architecture. From here, these signals eventually, reaches to the brain via spinal cord. In the brain, these are processed in the cortex and based on that, we identify a smell. So, this is the basic architecture of olfaction.

From here, we will move on to the next olfactory, sorry, next sensory system, which is our tongue. Think of it. Let us, first of all, try to practically understand it. You take sugar. Oh, this is sweet; one option. You take salt, you know this is salty. Now, say for example, you take something, which is a mixture of little bit salt and little bit sugar. You know, it is kind of a mix. How you identify all these things or you take say, vinegar or you go to a Chinese restaurant. They use all this kind of different salts, which gives a very pungent smell. Something or you go to have an ice cream. You can see, it is hot or something like that, maybe, it is cold. It has this kind of smell or likewise. So, how the tongue actually does all this things?

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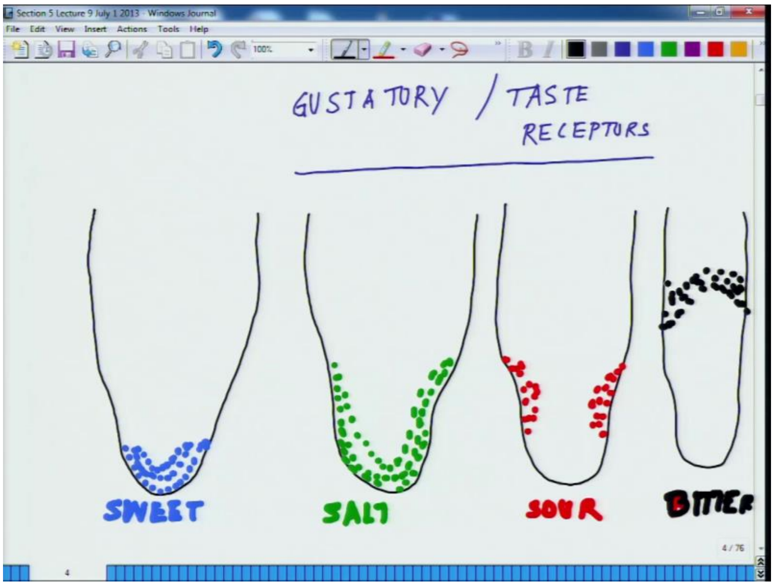

So, talking about, basically, it is also called a gustatory or let us call it as taste receptors. What I will do, I will draw the map of the tongue to give you an idea. This is how your tongue looks like. I am giving for all the different kind of situation; I am just drawing all the four. Say for example, when we say sweet something is sweet. Within this, there is a map, a specific region which gets activated, which is at the tip of the tongue. You can try out this experiment all by yourself. It is this region, which is mostly affected, when we talk about sweet; something is sweet. You take sugar and you put it on the tip of your tongue, and you will see that this part is the one, which senses the sweetness.

Now, there is next one which is your salty; something which is just reverse. Salt is tasted partly by the same region, but likely more. In the map, if you look at, it is the same region which is tasting, but it is much more spread out, as compared to the sugar. In between, there is another zone which is taking care. Let me write it down. This is salt and in between, lies certain region, which are say for example, you take a yoghurt or something like that; this is the one which is taking care of your sour kind of feeling. Yet, there is another region, which is taking care of your bitterness; something which is very bitter. Now that part lies somewhere, in the back of your tongue.

So, what essentially this means; this essentially means, these different areas of salt, sugar, sour, bitter; there is specific sensory neurons. Whenever, we eat something those molecules, which imparts out taste, those taste molecules goes and bind to those specific spots. Once they bind to those spots, they generate electrical signal. Those electrical signal again, follows the same functional architecture; from there move on to the spinal cord; from the spinal cord, they move on to the brain. Within the brain, if for that particular taste, we already have a stored memory, then it is fine; it is able to co-relate it; this is sugar; this is sour; and based on that, they say, this is ice cream, or this is mango or this is some other fruit, say for example, orange or something.

But, if it is not there, then new piece of information is stored. If it is there then it can; you are in a position to tell them. Then, you say, something like orange, but it is not orange. Mind it, whenever, we are talking about orange or say, mango, your always have to remember the other side. For that piece of information, there is not only your taste bud; there is visual information too. Whenever, we talk about the storage of information in our brain, for any specific thing, there are multiple ways that how we code that information. For a mango, there is a visual cue. You see a mango, you say, this is a mango, or you see a lemon, you say, this is a lemon; fine. That is a visual way of looking at it. But the same piece, when you taste, it has say, sweet, sour or bitter, whatsoever. That is another set of information; fine.

Now, for mango, we have one information which is coming from your tongue; one information coming from your memory, sorry, from your eyes. So, there are, for the same thing, when you have to decode all these things coming into your mind, you say, this is a mango or something, which is not a mango; but very similar to mango, you say, it is very similar to mango; or some other fruit; or some other food or anything. For everything, we have different special sensory modality. Based on which, we identify, this is mango; this is x y z; this is this; this is that; likewise. There are several ways, how we look into, like decode the information.

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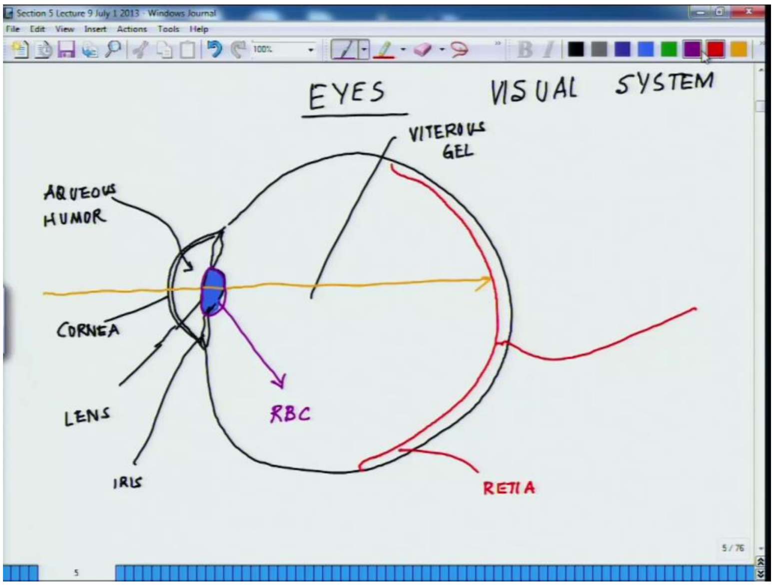

Now, after doing the olfactory and the taste receptors, now, what we will do, we will move on to the eyes, which is a much more complex system to look into; or the visual system. What I will do, the first thing I will do, I will draw the eye. That gives an idea exactly, how it looks like, at the structural detail. What you see; this structure is the lens, the outer most structure. It is actually, double layer. This is called cornea, which is divide of blood vessel; the cornea. This is a blank space filled with fluid called viterous gel or viterous space. Then, on the backside of it, is a thing called, this is your retina, which is drawn in red, and of course here, there is a spot from where the signal goes.

So, this is your retina and in between, there are few other things, which are very important. Just for your understanding sake. This is called aqueous humor. This one is called iris, which is holding just in front of the lens, slightly on the side and this is the lens. I am just putting the lens like this. It is a transparent tissue out here. What happens is that, when the light falls, light passes through this; passes through this; and then falls on the retina, likewise. Couple of things here, for you to understand, that I told you the cornea is a non vasculated tissue.

So, whenever you here about replacement; cornea replacement, those are much more successful because, there is no vasculature; there is hardly any reaction. Cornea from a donate person, who donated the cornea, is transplanted into another individual. The lens is a transparent tissue; this is the transparent tissue means, these are cells which are devoid of all the organals. Why is it so? It is a very interesting cellular process, and I will discuss this because, these cells which are present out here in the lens, follow the same routine as red blood cells.

So, in the next section, while I will be moving to about the cell types, I will talk about how these lens cells are formed, because lens cells and red blood cells follow the same pattern. At this point, just remember that these are transparent cells. They do not have anything so that, the light can pass through it. Otherwise, through a cell, a light cannot pass. Light will pass because, a lot of light will be lost, but here, nothing gets lost. In case, your lens has a problem, the option is, you replace the lens. That is what exactly happens in people, who suffer from problems; with blockage in the lens and all those things. Then, you have the retina which is this red patch, what I am putting here. What is the cellular structure of the retina, is most important part to discuss.

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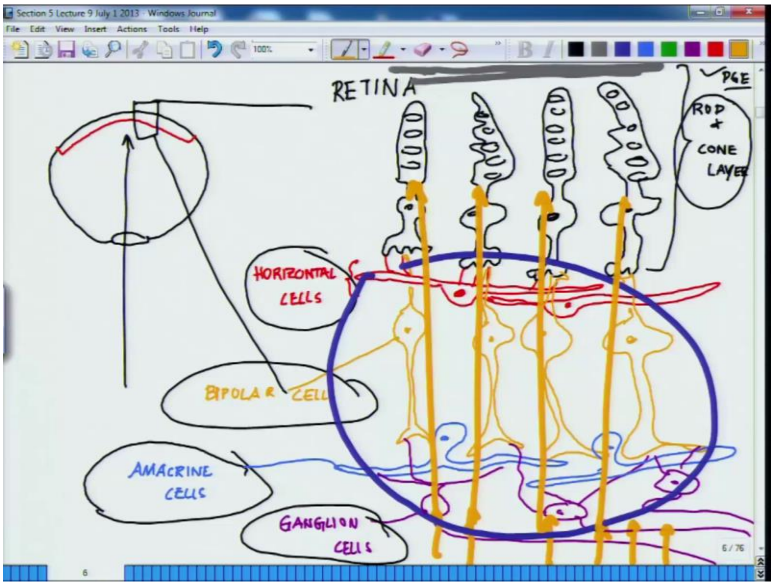

Now, I will move on to the structure of retina. Retina is again, just like the olfactory receptor or the taste receptors; retina consists of two specialized kind of cells, which could sense lights of different wave lengths. They could sense color. They could sense intensity of light. So, there are cells which could sense intensity, and those are called the rods; different light intensities, from very, you can see things in the dark; you can see things in the very bright. So, these are the rods which are helpful in figuring that out.

Yet, there are another set of cells which helps you to sense color. Those are called cones; Cones, c for colors, just for you guys to remember it. These cones are not active during the night because, if you realize in the night, without any kind of, if you are in a dark place, you look at the trees or you look at anything around you; it all looks black. During the dim light, during no light, almost hardly any light, you are totally dependent on the rods. If a system is adapted to live in the dark, they have a much well developed rod based system, as compared to the cone, where cone is not needed because, you do not have to distinct about colors.

Just for your understanding sake, those fishes or those species in the ocean, which lives at a further depth, do not have a well developed cone system, or they may not have even any cones in their system. Because they do not need to discriminate color, because the light does not penetrate through the water into, when it hardly penetrates to a certain depth. Beyond that, there is no light. You guys must have looked discovery channels or anything; you must have seen. Whenever, these people go inside the sea, they have this huge lights on their head, like, they should be able to see because, there is no light; sunlight does not reaches there.

There is a huge amount of animal species, which survives in that unfathomable depth of the ocean floor. Those species entirely, depends on their rod based systems; they do not depend on the cone. Because, they do not need any kind of cone support. So, this is to give you an idea, that these sensory receptors have developed, or because of our requirements in evolution, whichever condition we have developed, these sensory receptors have adapted. Their usage and their non usage is dependent on, absolutely on, what kind of physical modalities we have to detect.

With this small background, I will come to it; the circuit of the retina. I have already shown you the position of the retina. Now, I will draw the circuit. The circuit looks something like this. Imagine, I showed you the side view of retina. Imagine that I draw the eye like this, once again, and the light is falling like this. Here, you have the retina and now, I am drawing the cross section of the retina out here. It is something like this; they are the furthest layer, is called; these are the typical morphology of the rod cells. Then, you have, these are the cones; the rods. Just for the simplicity sake, I am only drawing four different cells here.

I will explain it; what does that mean. This is one layer which is called the rod and cone layer. Beyond that layer, there is something called red pigment epithelial cell. On top of this, you have another set of cells which are called horizontal cells, which are spread out like this. These are all different kind of neuronal cells, and they are forming synapses with. This is a horizontal like cell here.

Then, you have another; something called a bipolar cell layer. You have something like cells, like this. This is the bi polar cell layer. Then you have something called, are very interesting cell, these are called amacrine cells. We will talk about what are the functions of these amacrine cells. These are currently under intense study and then we have these are the ganglion cells. Let us start naming them. These red ones are the horizontal cells. Then, you have here, the bi polar cells. Then, you have the blue ones are amacrine cells, and then you have the ganglion cells.

If you look at the structure of the retina, this is a five cell layer structure. If you look at the absolutely furthest layer, say, that is the back, which is retinal pigment epithelial cell, which is out here. I shade it for you; this is that layer. This is the cell layer which supports the rods and the cones. Then you have the rods and the cones layers; they are two out here; layer three of the horizontal layer; layer four of the bipolar layer; layer five, one, two, three, and four. Layer five; amacrine layer and layer six, which is the ganglion layer. It is very beautifully arranged. If you take a cross section of the retina, it is very beautifully arranged. The light is falling; this is light is falling from this side; light is falling like this. One second, bare with me. Light is falling like this. So, light passes through these and because, none of these cells in between, have any kind of sensory receptors out here. So, the light reaches all the way out here, and from here, the signal transaction starts.

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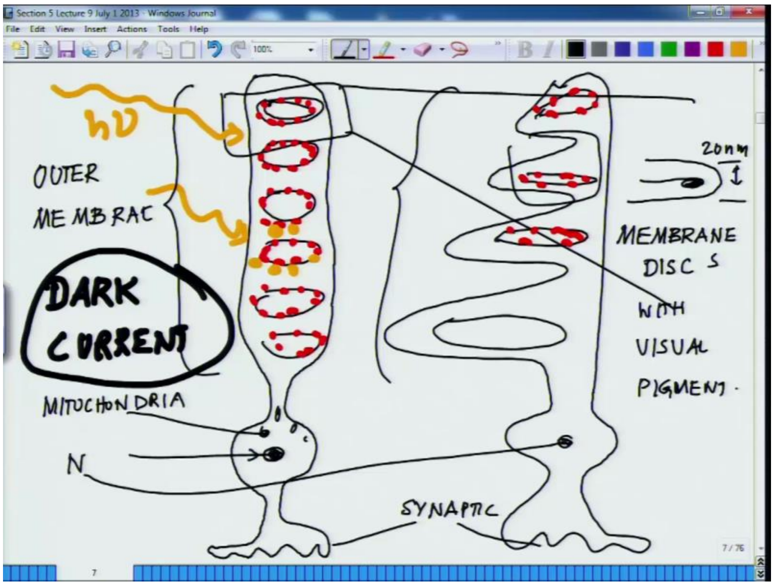

What essentially happens is this. Now, if we look at the structure of the rods and cones, in further details, while I was drawing that, I told you. I will come back. There are some very intricate details which need our specific attention. This is a classic rod, what I am drawing now. This is how the rod cells are. Then I will follow the cone, which is more like, is a membrane structure out there. This is called the outer membrane of the rods and cones; both for them, this is the outer membrane. Here, we have lot of mitochondrias and here, you have the nucleus; nucleus same for both of them. You have lot of mitochondrias and this is the synaptic zone. This is where it is synapsing with the next layer, which if you look at the picture, it is synapting in the horizontal and the bi polar cells at this layer. So, mind it, they are always synapsing on multiple cell types. It is not only synapsing on one cell type

Coming back, these are the synaptic zone and this is the zone, if you look at it in further detail; if I blow this up or blow this up, this zone is something, like membrane disc. It is something like this, and this dimension is around 20 nanometers; from here to here, around 20 nanometers. This is called membrane disc and there are great number of membrane discs out here, which you can see. Just for simplicity sake, I have just drawn few of them; membrane disc with visual pigments.

So, this is basically, essentially, the architecture of the rods and the cones. What is exactly happening is this. In this zone, if I further blow this up, there are receptors which are sitting like this. The receptors are sitting like this. All the red spots are the receptors on the membrane, and same for the color for the cones.

Now, what is happening, when the light is falling, here is a light photon; nu, light is falling. Whenever, the light is falling, these bind to these receptors; the photons, likewise. When the photon binds, that leads to electrical signal. This is how it works. Here, there is something which you people have to realize; this is something called a dark current. What does that mean? You understand this concept, then you will be able to realize. Under normal conditions, when light is not falling, say for example, it is normal, suppose, I am in a dark place and light is not falling on me. These neurons are sending signals to the next layer, without any ligand; no light is falling. As soon as the light starts falling, they stop sending the signals. In other words, what is happening is this.

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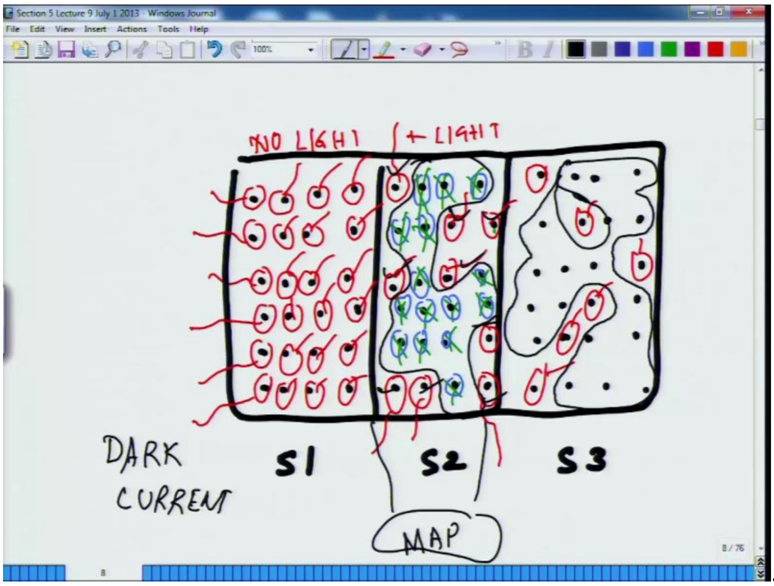

If I draw it, say for example, this is a matrix, I am drawing and let me put it like this. Let us see situation 1, situation 2 and situation 3, and these are the sensor elements. These are the sensor elements and I have a repetition here; 1, 2, 3, 4; 1, 2, 3, 4; 1, 2, 3, 4; 1, 2, 3, 4; 1, 2, 3, 4; 1, 2, 3, 4. This is the same panel, which is now, in the dark. So, all of them are under this situation. All of them are active. This circle means they are all active and there is no light. We put it no light and imagine, these are the different rods and cones which are sitting here; it is just for simplicity sake, think these are all rods which are sitting there; no light; all of them are active. They are sending certain signals.

Now, light starts falling; now, plus light and other photons are started binding. So, light falls differentially at different. Now, the one, which is blue on which the lights are falling. Here, there is no light falling; here, there is no light falling; no light falling; no light falling; no light falling. Now, these are the ones where the light starts falling. The photons are binding to these ones. As soon as the photons are binding to this, the signals which it was sending; these are the signal which are being sent in stage two; and this one, these neurons are no more; no signal; no signal; no signal; no signal; no signal; no signal.

Now, in this situation 2, you see a pattern; this is active; this is active; this is active; this one, this one is active; this one is active; this one is active; active, active, active, active, active, active, active, active. So, this creates a map now, about the structure, which you are trying to see. The current, which are being sent, when during no light situation, is called dark current. It is just what is reverse. Remember this; this is very important. If I go back into this picture now, whenever, the light falls, they bind and the signal seizes to move. When the light is not falling, the signal is there on the process. It is just the reverse of it. This is how and that is why, it is called the dark current. This is the way you have to appreciate it. So, this is the situation 2. There could be a situation 3, where the light is falling at other; it makes a different kind of map.

Say for example, now light is only falling to these six signals are going, and all the rest are no more active. You create a different kind of map like this; the map which is getting formed is something like this, or something, which will have to exclude this one, somewhere or other. Think of it. So, this is the new map which forms. Before this, the map was something different; the map was like this. Look at the two structures. They are different. This is exactly, what I am trying to tell you. It is just like, say for example, those of you have gone to see these cricket matches or something, in a flood light panel. On a flood light panel, I can make an m, or I can make a d. I can make an a, I can make an q, I can make an z; by switching on, switching off certain lights. You can see a pattern out there, likewise. I can switch off certain light, I can switch on certain light on a panel; that is exactly, the retina is all about and if this concept is clear to you people.

Now, if you look at the structure out here, this whole complex circuit, if you look at this complex circuit, this complex circuit is nothing, but a panel. As long as this you understand, it as a panel; this will make more sense to you people. Then, grasping through all the nitty, gritty details of cellular geometry, which will not make sense. You have to understand that always think of the analogy of flood light in any place. There is a panel of flood light; you can switch on and switch off light, and make a pattern of that; you can make a; you make z; you can make q; you can make 8; you can make 9; you can make 1; you can switch off all the lights and still, you have the one; like a central line, that you can make an I, like this.

Just exactly is the retina is all about. It creates a pattern and that pattern goes all the way to your brain. The same way, it creates a color coding using your cone receptors. So, the cones help in the color, but in the dark there is no color. This is basically, what I expect you people to appreciate and understand. This is a very fundamental concept of the way, we store visual information. As long as, that is clear to you people, rest is all cakewalk. Then, you can grab anything or any books; you can figure it out exactly, what is happening. End of the day, it is the coding of ionic electrical fundamental, which is stored in the brain and again, the same thing happens. These ganglion cells, through spinal cord see reaches the brain. That is it; through spinal cord to the brain, and from the brain, they got decoded and you know, that this is 1; this is 8; this is 7; this is 6; this is n; this is q; this is f; this is m; likewise. So, this is what I wanted to cover on, about the eyes.

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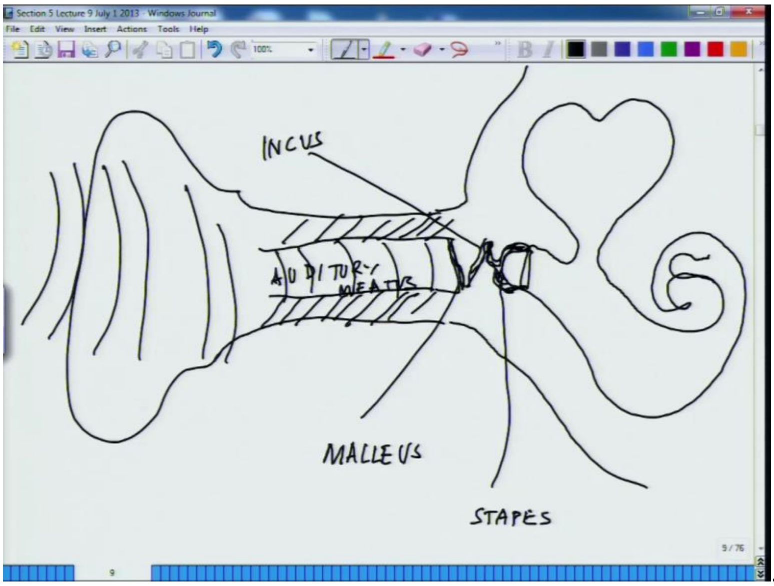

Now, I will go on to the third modality, which is your hearing modality. This almost follows the same thing, but they have a slightly different geometry. That is what, I am going to discuss now. Those of you, we have two ears. If you look at the way, let us do once again, the way it is, it is basically the sound waves, which are moving out here, through the canal it moves all the way inside. So, the way it works is this. These are the sound waves, which are coming. There, you have an ear conduction zone out here; it is a boney matrix; out here, it is very boney. Then, out here, it hits upon three specific bones; the sound hits upon three specific bones. The first one is called malleus, second one is called incus, third one is called stapes; this is the third bone, which i am drawing now, called stapes. Sometimes, this is also called auditory meatus.

Now, from here, starts the journey of the sound waves, as it is moving throughout inside the ear. After it crosses this, it goes inside the cochlear. This is the zone which is very important for us. The structure is a very, if you look in the picture, it looks like a very complex structure, but we will come to that. Actually, this is not exactly, sorry, is actually, more like this. Do not get worried about this structure; I will just try to tell you something, before I draw this structure in depth. Whenever, you hear a sound, you hear a piano; you know this is a piano; those who have some sense about a sound of musical instrument, or you hear a drum; you say that is a drum beat or you listen to saxophone; you say that is a saxophone, or you listen somebody has filled the glasses with different amount of water, and there is that tinkering sound; you could figure that out; somebody is creating those sounds, or you create a whistle; you know the sound. So, this whistle, shrill and all these things; you understand all these things. What exactly that does mean. If you look from the electronics perspective; that means, you have a sensor which should be able to sense the different sound frequencies; that is very important for you, or different sound frequencies or different wavelength of sound; there at only two ways you can figure out a sound, either you know the frequency or you know the wavelength. Based on that, you should be able to figure out what kind of sound is that.

If you look at the keyboards, any keyboard, you play on a keyboard. So, you do it like the [fl] or like, if you heard the western music, you say [fl] likewise. So, every time you bang on to a specific key, it creates a unique signal. Based on that, you compose a song; you know this frequency; this frequency; this frequency. So, based on that, you create a specific kind of node; a specific kind of line. As long as this concept is clear, then ear is a very simple thing.

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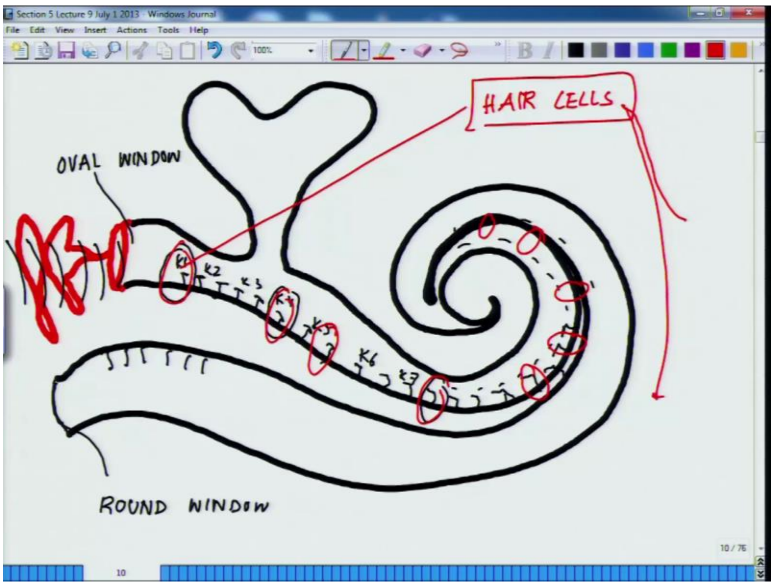

Now, I will come back to the cochlear structure, which I told you that this is a complex structure, but do not worry. We keep this background in mind. The structure of cochlear is something like this. Do not worry about this part, what I am drawing in the top. Because, that is involved in all the balancing act and this tube is more, like this. Now, with respect to stapes, which is the last bone, it is here and here, you have the incus and here, you have the malleus. This one is called oval window; this smaller finer tip. This one is oval window, and this one is called round window. Sound enters through this, likewise. From here, this sound is entering; sound waves are entering here.

Now, all along this path way, what you see. There are specific cells which are sitting like this. Now, when I am drawing this, I will draw your attention to a keyboard. Imagine this, what I am drawing now, as the as the keys of the keyboards; say for example, I am putting the k1, k2, k3, k4, k5, k6, k7, likewise, all throughout their line like this. So, whenever a sound wave enters here, these keyboards, based on the frequency of the nature of the sound; frequency of wavelength, they get activated. These specific components of the keyboards of the ear are called hair cells. They have nothing to do with your hairs; they are very similar to that; hair cells. Similar to, in terms of their structure. They are called hair cells. These hair cells are the ones, which are a very specialized kind of neuron; just like the rods and the cones, which code for specific sound frequencies and wavelengths.

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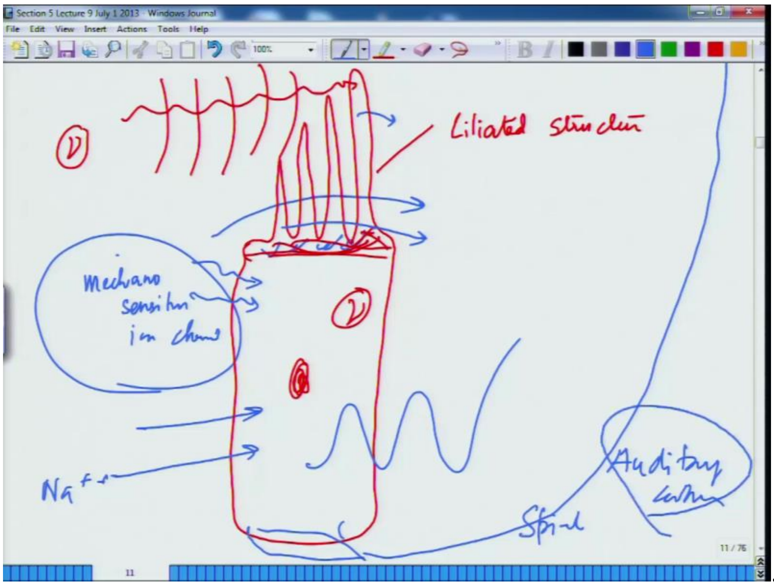.

Now, how the hair cells structures look like; something like this. If you draw hair cells structure, it is like this. This is how the hair cell structures look like. They have ciliated structures like this. Whenever, there is a sound wave hits upon, either they bend, they all. These are underneath; these are connected by different cytoskelatal cell protein. Whenever, a sound wave hits a specific chord, and if this particular hair cell which I have drawn, is coded for a specific frequency. So, this frequency matches with this frequency out here. They all bent in one direction. They all bent in something, like this; if this bends in one direction, it will pull along with it; it is kind of a spring; it will pull all of them together on the other direction.

As soon as they pull, there are something called mechano sensitive ion channels out here. Mechano because; there is a mechanical motion here. As soon as this mechano sensitive ion channels gets activated, this leads to the flow of sodium ions inside it. As soon as the sodium ions go beyond the threshold, it generates an action potential. And this underneath is connected with another set of neurons, which takes the information to the auditory cortex in the brain, through the spinal cord. Through the spinal cord, it takes to the brain. Now, if you go back to the previous diagram, from here underneath, there are these circuits which are sitting, which will eventually, take all the information from here to the brain, likewise. Whatsoever coding is taking place at different points, are getting or sent to the brain, for further processing. This is all about how it works.

Now, in context of it, you replace this whole thing. We replace this whole structure; imagine, you have this keyboard sitting here, with different keys. These are the green color and the keys are connected to your brain, likewise. That is exactly, so, you hit upon a specific key; specific signal, hit upon another key, and another specific signal and moves on. So, this is how the ear is coding all the different pieces of information and we hear. Based on this coding, there is memory storage in the cortical region of the brain, which helps our helps us to decode, that this is the voice of your mother; this is the voice of your friend; or this is the voice of bird; or this is a vibration from some x y z sources.

Now, to summarize what all in the special senses, we covered; we talked about the olfactory sensors, where you smell the volatiles; we talked about the taste buds, where we taste specific things; specialized cells; specialized neuronal cells, which senses it; we talked about the rods and the cones, which carries the information to the brain, which are specialized neurons, in terms of visual information; and then we talked about the hair cells, which carries information or vibration of information to the brain and thereby, we hear. And what I expect, you have to have a simplistic outlook to look at it, that every information, every modality, every special sense modality which is reaching to your brain, is being stored for the specific individual piece of information in several ways; it could have a visual component; it could have a hearing component; it could have a taste component; and x y z. Based on that, we developed that concrete memory about that x y z individual or x y z object. It is a very wonderful combinatorial information storage mechanism, which mankind is trying to understand; what we started in the beginning, that is, what we call as a neural code. From here, we will talk how the tail pieces will be sympathetic and parasympathetic systems. So, I will close in here.

Thanks a lot for your attention.