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GERALD SCHNEIDER: We were talking about channels of conduction. That is what happens to sensory inputs when they come into the nervous system. We talked about the local reflex channel involving, say, segmental reflexes or intersegmental reflexes, which I didn't put on this list here, the concepts of the dermatome and a myotome.

Where are the local reflex cerebellar and lemniscal channels in the Schmoo brain? Well, let's do it here. Get a color you can see here. So here comes the sensory-- oops, too big-- here comes the sensory input here, and it's going in, and it's contacting all these secondary sensory neurons. We can color them here.

Now the question is, where do they go? Well, this would be the example of the local reflex, going through an [? enteric ?] neuron here to the motor neuron out to the muscles. That would be a segmental reflex. It's all happening in one segment of the spinal cord.

I don't show there that pathways can branch. They can grow to other levels of the spinal cord. And we can get intersegmental reflexes, too.

So the cerebellar pathway-- I'll put it in green here. Here it goes, a pathway into the cerebellum. And I said that all sensory systems have such a pathway, that we think that maybe olfaction is an exception. At least those pathways are less direct for olfaction.

But there are visual system inputs to the cerebellum. There are auditory inputs to the cerebellum, many somatosensory inputs like this one, certainly proprioceptive inputs. What about the lemniscal channels?

Well, this would be an example of the lemniscal channel, something that goes above the chord itself. And I'll show in the Shmoo brain here some axons that are going rostrally into the brain. So those are the lemniscal channels.

It helps to bring color pencils here. I mentioned that once before. If you've got a tablet PC, of course, you can do the same thing I'm doing here.

This is where we finished last time. We talked about how they map the dermatomes, irritation of similar roots causing hypersensitive regions in the skin or areas that remain sensible when adjacent roots had been eliminated. So what's a myotome? It just means muscles innervated by a single central root, and pretty much they correspond to the dermatomes.

So when we talk about these lemniscal channels, we're introducing additional terms. I talked about what we meant by suprasegmental, above the spinal segments. Now let's look at that pathway again, and you'll hear me mention the reticular formation, the thalamus, the [? kesation ?] and a few other terms. If I mention terms you're not familiar with, please stop me and get me to define it.

Now, the pathway with the lemniscal pathways I've shown here, we group them together, call them the old lemniscus, the old ribbon, and the paleolemniscus. It's just another name for it. The most common term you'll find among neuroanatomists is to call it the spinothalamic tract.

Many tracts in the CNS are named just for their origin and their termination-- in this case, the most distant termination. So they start in the spinal cord, as you see there. And they end here in the thalamus.

This is the thalamus. It represents the thalamus, we should say. It's a fairly large part of the twin brain or diencephalon.

But note here that it's where the longest axons end. Many of them are not ending there. So just because we call it "spinothalamic tract" doesn't mean that all the axons are spinothalamic.

Well, where are the rest of them terminating? Well, most of them are terminating in what we call the "reticular formation," which means brainstem structures where it's difficult to specify a clearly defined nucleus, sensory or motor nuclei, or other structures. It's a network of cells and fibers that form a good part of the core of the brainstem.

The neurons in the reticular formation get many different inputs. Some people say they get diffuse inputs. And yet that reticular formation controls very specific functions. That's where we have the circuitry for fixed action patterns, for example. That's obviously very specific, inherited behaviors.

So here it shows them coming into the hindbrain, into the midbrain, and some of them go into the optic tectum or superior colliculus, the midbrain, which gets a lot more than just visual input, although we call it, usually, the optic tectum. Because in many species, it does get visual input. It's superficial layers and it's dominated by the visual system in many animals.

Now let's look at a more realistic view of the mammalian nervous system. Remember, this was a picture of the embryonic neural tube with the hemispheres growing. Let's look at that, and I ask you to pretty much learn this. Learn both the English and the Latin names for the basic subdivisions. And you'll learn these cross-sections because you'll be seeing them many times.

So here, I put it on its side so it's oriented the way the Shmoo brain is now, the caudal end to the left. Of course, I've exaggerated the relative thickness of the spinal cord and brainstem here. But now this is that same pathway, the spinothalamic tract.

So where is it starting here? What is this? Surface, the body someplace, like skin. And where is this neuron? Dorsal root ganglion-- there's not one of them. There's many of them. There's one for every segment.

So it's a dorsal root ganglion cell, also known as what kind of a neuron? Primary sensory-- primary sensory neurons are the-- cells are always outside the central nervous system, and their axons end in the central nervous system. So here are the secondary sensory cells.

And we'll see that immediately, right there at the level of the spinal cord, the secondary sensory cells send their axon across to the other side. And that's the decussation, where it crosses. When the pathway decussates, it means it just crosses to the other side before it goes where it's going to go.

So that means that input coming in the left side of your body is going to be represented on the opposite or right side. If it's coming in the left side, it's going to be represented on the right side of your brain, as you see in the pathway here. And here, we see the connections in the reticular formation and colliculus, but the longest axons are reaching the thalamus.

I'll put that one in blue. There's a neuron in the thalamus. And many neurons in the thalamus are projection neurons. They project up to the end of the forebrain. And I'm showing one here that's characteristic of mammals, that goes up into the neocortex.

Now, the Shmoo, which was, remember, a characterization of a more primitive ancestral brain, has little or no neocortex. It also has a spinothalamic tract, and it has the thalamus. So where would those axons go? Well, they go into the corpus striatum.

I'm going to give you-- I hesitate to give you too much anatomy all at once. So we're going to take a little break and talk about function. Question first.

AUDIENCE: [INAUDIBLE].

GERALD SCHNEIDER: Big question. Some people always ask that question and there's never a totally firm answer. Why do we have decussations in the first place? Well, first of all, not all pathways are decussated, and then the second answer is, we don't really know, but it happens.

Cajal said that without decussation, you couldn't have as coherent a representation of the visual world in the optic tectum. I won't go through that whole hypothesis right now. I do it in 914. One of the teaching assistants asked me-- no, it was a teaching assistant from last year-- asked me the same question and I gave him an answer. I'll pull it up and post it, if you want. You can see what I told him.

So this is what we're going to talk about now. Probably it'll take quite a bit of the remaining time. I want to ask what an animal can do if it doesn't have a forebrain.

So those long pathways, the lemniscal pathways reaching the end brain in particular-- what if he doesn't even have the end brain there? Or what if he doesn't have any forebrain at all? So we'll talk about chronic decerebrate animals-- animals that have been decerebrated because they've had their forebrain lopped off in surgery. And this has been done in experiments with cats, rats, and pigeons.

And then we'll talk a little bit about what happens if you do that but you leave the entire corpus striatum, or if you leave the striatum and the limbic structures? Can the animals do more? And then I'll talk a bit about some complications of these experiments.

I didn't put all the references in here. I was going to do that and I forgot to do it before the class. But I can add those, if you want, later on.

The Bard and Macht experiments were very well known and very influential. They basically took cats, took off their entire forebrain surgically, kept them alive, studied their behavior as they recovered. Now first of all, they were blind and anosmic. Why? Why were they blind and anosmic? They couldn't smell, they couldn't see. Yes.

AUDIENCE: [INAUDIBLE].

GERALD SCHNEIDER: But you remove the visual association cortex, certainly, but that's not why. You can see a lot without the visual association areas.

AUDIENCE: [INAUDIBLE].

GERALD SCHNEIDER: The optic nerve comes in. Really, the optic nerve is a tract of the central nervous system because the retina is part of our brain. It's part of the twin brain, the diencephalon. That's part of the forebrain.

Because they severed just behind the twin brain, there was no way for these first two cranial nerves, the olfactory and the optic, to influence behavior. Because behavior is controlled by motor neurons, and the motor neurons are all in the midbrain and more caudal. So first of all, they were blind and anosmic.

But animals, of course, that are blind and anosmic, can still do a lot of things, if that's all the problems are. But their problems were much greater. They didn't eat spontaneously. In order to keep them alive, they had to force feed them. If they put food in their mouth, they could elicit chewing and swallowing movements, so they could keep the animal alive that way, by force feeding.

They didn't groom themselves, so they were looking pretty bad. They had to brush them, take care of them. The only cats that won't groom themselves are very sick cats. These cats didn't act like they were sick. They just didn't have the ability to groom.

They didn't have any spontaneous social behavior, including sexual behavior. And yet they did have reflexes associated with those things. They could stimulate the genitals and elicit sexual reflexes, but they didn't show any spontaneous sexual behavior.

What about other behavior, as well? They could stand up. They could right themselves. They could sit. If you push them over, they would stand up again.

They could walk. They didn't seem to initiate walking, but if you nudged them along, they could walk. Their gait and posture wasn't completely normal. They would leave their limbs in odd positions.

But they had more complicated behavior than that. If you pinch their tail, they would fly into a rage. But they called it "sham rage" because they didn't bite, they didn't strike out. They didn't show some of the directed behavior of an angry cat, but it was clearly a rage response.

They also showed some autonomic responses. If they got very cold, they would show piloerection. That is, the hairs would stand up.

Thermoregulatory responses weren't completely normal. The temperature deviations had to be pretty extreme, unless they left the hypothalamus intact. So some of these studies have been done with a similar lesion, but they leave an island of hypothalamus.

Hypothalamus has some of its connections, you'll remember, through the bloodstream. And that's very important for keeping decerebrated animals alive, making it much easier to take care of. So normally when they do this, they leave the hypothalamus intact, but they disconnect it from its descending neural connections.

So this is the way Bard and Macht summarized their results. They said it was a-- I don't know if I put it here. Well, they said it was a "purely reflex animal." It had the various reflexes that they could test.

They said it failed to do any act that required the performance of a series of reflex in proper sequence. That was their characterization because all they saw was these isolated reflex-type movement patterns. And they also said maybe they didn't learn anything. That's a more complicated question because learning can take place at many levels in the nervous system, although most of what we ordinarily call learning does require the forebrain.

So what about other animals? What about the rat? And now we get into some interesting questions that I will have to spend the rest of the time here talking about.

But first, let's just tell you what rats and pigeons are like without the forebrain. And then we'll discuss why they're so different. If you do this to a rat, it's similar in many respects, but there was a more-- first of all, they recover more rapidly.

They recover their righting, recover their locomotion faster than the cat did. But they show more eating and drinking responses. They didn't seek food, but they showed more of the responses.

They did groom themselves, so there's something wrong, then, with the summary of the cat behavior that remember, the people that studied cats said they didn't show any complicated sequences of movements. But the rat can groom himself, even without a forebrain. Also, his eating and drinking required more complicated series of movements.

Defensive behavior-- you get them upset, you pinch their tail and so forth, they showed more typical rodent defensive behavior, including biting. The cats ate only if you put the food right in their mouth. The rat would do more than that.

The rats even showed some auditory localization to sounds around them. Well, so the rats do more. And we have to ask why.

Well, we say, a cat is a more advanced animal. Its behavior depends more on the forebrain. And that was what you usually said. They said the function had become encephalized, encephalization of function in evolution.

And I'll explain to you why that wasn't a very entirely satisfactory explanation. But first, a little bit about pigeons. Do the same thing to pigeons.

Now here, we have to be careful because pigeons depend so much on vision. If we want to study the behavior, we'd better spare those optic tracts. But we will still eliminate everything else. We'll just leave the tracts connected to the optic lobes in the midbrain.

These studies were done in the '30s. I read them in German when I was working on a PhD thesis here at MIT. These animals basically had a basic repertoire of what we call the unlearned reactions of pigeons.

You could take the pigeon and throw him into the air and he would fly. He wouldn't initiate flying, but he would fly if you threw him into the air.

Not only that, but as he was flying, he would avoid vertical sticks that you put in his way, and he would land on horizontal sticks. He would also land on the back of a dog or a cat, which a pigeon doesn't normally do. So they have many more complicated behavior patterns, even some of which depend somewhat on learning.

This is the way Nauta characterized the forebrain functions more generally. He said the animals without the forebrain have good stability in space. And the stability of their internal milieu is pretty good, too, at least if you leave the hypothalamus intact. But it doesn't need its neural connections to the brainstem and spinal cord to do that. Yes. Sorry?

AUDIENCE: [INAUDIBLE].

GERALD SCHNEIDER: Define stability of the internal milieu? I mean temperature regulation, regulation of blood pressure, heart rate. That means maintenance of blood glucose levels, temperature regulation, the various things that are important to maintain life, but basically involve the vegetative or autonomic nervous system.

So they have these things. But he said what they don't have, none of these animals have very good stability in time. Behavior is just determined by what's happening right now, current inputs, little or no motivation-initiated behavior, little or no long-term memory. And I think Nauta's characterization put in these general terms is still correct, but we still have to deal with these species differences.

We can spare the corpus striatum and we get more behavior. The cats show more grooming. They show spontaneous eating if the corpus striatum is intact. And they show some mating behavior. They're a little more like the rats without the corpus striatum, as I point out there.

So why this species difference? That's the question I'm getting to. The answer is one that's confused a lot of people-- in one word, [? diathesis. ?]

This has to do with the quantitative effect of large lesions. We summarize it by saying it's deafferentation depression. If you remove a lot of excitatory inputs from cells, the cells can generate action potentials, at least for a while.

Let's give some examples of that. We'll talk about spinal shock first of all. Say we sever the spinal cord in the mid thoracic level, and we're going to look at reflexes of the legs, all controlled by-- we'll just look at segmental reflexes of the legs, so it's controlled by the spinal cord caudal to the middle of the thoracic segments of the cord.

If we cut descending pathways, the animals lose reflexes controlled by the spinal cord caudal to the transection. And why would that be? The pathways, we know, are still there. Why would they lose spinal reflexes?

It's called "spinal shock." It does recover over time. The fact that it's lost is what we're concerned with here, and it's lost for a longer time in the animals with the greater number of descending connections. It's like the more you remove, the longer it's lost.

Von [? Monaco ?] was the first person to define this in very precise terms. And his papers on it are very clear. I read a paper of his in German where he discussed corticospinal [? diathesis. ?]

I found out that neurologists and almost all neuroscientists had never read that. Most of them don't read German, but for some reason, von [? Monaco ?] was forgotten about, and they talk about [? diathesis ?] as if it's almost like some mystery. It isn't, really.

He described, for example, corticospinal [? diathesis. ?] If you remove, do large cortical lesions in an animal with a lot of cortex, you can lose spinal reflexes, even though those reflexes don't depend on the cortex. Why? Because especially in the animals with a lot of neocortex, there's a lot of excitatory connections to the spinal cord coming from the cortex.

So if you remove them, the cells losing so much excitatory input can't reach threshold anymore with the remaining excitatory inputs. But they do after a while. And how long it takes them to recover depends on how much input you've removed.

We know of two mechanisms that can explain the recovery. One of them is that the remaining inputs, the axons carrying inputs from other sources, will show some sprouting. They'll increase their connections. That's collateral sprouting. We'll be talking about that a few times in the class.

And the other one we call denervation super sensitivity. The cell having lost, say, a lot of inputs that use one neurotransmitter-- say it's acetylcholine-- will increase the number of receptors for that neurotransmitter. So they'll become more responsive to the remaining ones. And there's good evidence for both of these processes in the spinal cord.

But now, the basis of [? diathesis-- ?] what I've shown here is a little diagram showing-- we'll call that cortex up above. And so this is to represent cortex in two species, one animal, say, like a cat with a lot of cortex, another animal, like a rat with less cortex, or a pigeon with almost none. And this represents, we could call it, a reflex pathway through the spinal cord. And we'll just let all these be excitatory connections in order to simplify things.

So these show the connections in two species. And now we make a lesion. We just eliminate the descending pathways.

So when we do that, we've tremendously reduced the number of excitatory connections down on the cord. But we removed many more in the animal with the larger forebrain. So now, we've got our degeneration.

And I changed the color here because the effect on these neurons in the species with the larger cortex is going to be greater than on these, because more excitatory connections are gone. So it's going to take a longer for this cord, this large structure, to recover due to the collateral sprouting and denervations for sensitivity, than this. And I can tell you also that there are cases known from our recent studies where [? diathesis ?] can be permanent. And when we talk about visual system, we'll describe some evidence for that. In the case of spinal cord, it never seems to be permanent. Yes.

AUDIENCE: [INAUDIBLE].

GERALD SCHNEIDER: It's a good question, but we can explain most of the [? diathesis ?] effects just in terms of the excitatory connections. So that's why I don't complicate it with inhibitory connections. Inhibitory connections may be less involved because they're always made through interneurons, and the interneurons are all intact here.

What did I do-- here we are. So here's a neuron. Here's descending connections. In our little cartoons, we represent excitatory connections that way. If it's inhibitory connection, I'll draw it like that.

Now, let's eliminate that. What happens? Many neurons will then sprout extra collaterals, like that, literally grow more little terminations. Collateral sprouting can be-- we sometimes call it "terminal sprouting" if it comes right from the terminals themselves. But in many cases, they look more like just extra end arbors.

And denervation super sensitivity we'll represent here as just increased numbers of receptors. That could be the normal, and now we increase the numbers of receptors. It's going to respond more to the neurotransmitter if it's got more receptors.

I can't say that I'm satisfied with the number of studies of those processes. So there are many details we don't understand. But I think the evidence is pretty good that both of those things happen.

And I'll say one other thing about the recovery in the spinal cord, and this is very important in the neurology clinic, is that a patient who has lost many descending connections due to a spinal lesion, as his reflexes recover-- and remember, he doesn't have higher control over them now, but he's got the spinal reflexes-- that recovery goes too far in many cases. And so the reflexes become spastic. That is, they become overactive. And in only fairly recent years do they have drugs that can reduce the sensitivity of reflex to reduce the spasticity. So we'll have to start there next time.