GERALD SCHNEIDER: I'm not going to go back over the neuroanatomy, although it will come up again at the end. This is what I talked about before, residual vision after ablation of primary visual cortex. But let's just review very quickly the early studies and the hamster studies, and then we'll focus on the rhesus monkey and humans without striate cortex and a little bit about some other species.

Remember that initially, it was said that people without visual cortex have a kind of blindness. It was called cortical blindness. They had a sense of light and dark but didn't seem to have any spatial vision. And that was studied formally in the monkey by Heinrich Kluver at the University of Chicago, and he concluded-- using a discrimination technique where the monkey had to choose one over pair of stimuli in order to get a reward-- he concluded that they just didn't have any object or shape vision at all, though they could do the discrimination lighter things from darker things.

And similar studies were done on the rat around the same time by Lashley, Karl Lashley, the guy who we often call the founder of physiological psychology as a science in the 20th century. And he concluded that they also lost all their pattern vision. They couldn't discriminate upright from inverted triangles. They couldn't discriminate horizontal from vertical strips. But they could do light discrimination of light-- a light door from a dark door.

They were paying no attention to the less formalized testing that had been done in this study that I found written in German published in a Dutch journal. It was a study in the 1930s of rabbits without the visual cortex. And when I read that, I got to reading it because I was making some observations on hamsters without visual cortex. Looked to me like they did have some vision.

And I found it in this study also in the '30s. They would respond to the visual appearance of people that had their food, and they would come running over. They were much too far to smell it. Now, rabbits have very good hearing, so it seems possible that they weren't able to completely separate the role of hearing.

But people basically ignored this study. And so I think I reviewed a little bit about the study of the hamster's two visual motor systems. We say that a double dissociation was obtained. That is, the consequences of lesions of the visual cortex were different from the consequences of lesions of the colliculus. One lesion caused a problem with one test and not the other.

The other lesion caused the problem with the second test and not the first. And this was the diagram I used to summarize that. And here, I've added the lesions. So the lesion we're talking about right now is this lesion, the ablation of the striate cortex, which gets its input from the lateral geniculate body the thalamus. That's what LGd is here-- LG for Lateral Geniculate, D is for Dorsal because there's two parts to that nucleus.

But notice that the retina has another major projection. It's even bigger. And in the hamster, in fact, it's three times the volume. The area of termination is three times the size of the geniculate in the anatomical studies that I was doing.

And these lesions had a totally different effect. And I'm going to go back over that. I will describe the kind of disorientation these animals had after we finish talking about visual cortex lesions.

But basically, the colliculus lesions abolish the animal's ability to orient, to find anything by means of vision, but didn't cause a problem with the pattern vision, whereas the striate cortex lesions, just like Lashley had concluded, these animals couldn't do pattern vision, but they did have orienting movements.

Now, you don't see orienting movements if you put the animal in a problem box and run them through tests. You have to work with them, figure out ways to-- there are now more formal ways to study orienting, but there weren't at that time. But before we go back to these little animals, let's talk about the consequences this had for monkey studies.

You remember, people had concluded from the studies of monkeys that they didn't have spatial vision, although Larry Weiskrantz, a neuropsychologist in England, had done studies where he showed that monkeys and also rats could discriminate, say, a speckle pattern from a gray if the average luminance was the same. But he thought that the reason was is that simply elicited more retinal activity if there was a lot of contour in the field. So that was the only additional finding to the earlier studies of Lashley and Kluver that said they only had light/dark discrimination ability.

These are pictures of the monkey brain. And if you look at it from the side, this area behind the red dots here is the striate cortex in the monkey. In human, very little of it would be seen from the lateral surface. But you would see it on the medial surface. Here's the medial surface of the monkey, where you see striate cortex in this region in the back here.

So all that other cortex shown in the color there is also visual. How do we know it's visual? Well, by two means. One is if you record from it, you get responses to visual stimuli, but you get some responses to vision in other areas too. But the main areas responsive to vision are the areas shown in this-- I don't know what to call that color-- sort of a pink-orange.

The other method is anatomical. If you study the projections of the striate cortex, you find that they project transcortically to areas nearby. We call those juxtastriate areas, areas next to the striate cortex. And then if you study the projections of those areas, you find that they go down into the temporal lobe. Now, there are other projections that go across dorsally that aren't shown here that go into the prefrontal cortex, this region right up here, in front of the motor cortex.

So we're going to talk about animals with lesions of just this striate cortex, the area defined as the area that gets projection from the geniculate body of the thalamus. And you can judge the completeness of a lesion like that by looking with a cell stain at the geniculate body because they undergo retrograde degeneration when the corresponding region of cortexes ablated. And that's generally true for many of the cortical regions. That's the way that, initially, the thalamocortical connections were mapped out. They were done with retrograde dressing techniques.

So first of all, after the hamster studies, the investigators in England made it clear they were making striate cortex lesions in monkey and had just concluded these studies of the speckle pattern versus the gray. So another student of Weiskrantz, Nick Humphrey was his name, still active in research in England. He made striate cortex lesions. And he spent more time with his monkeys. He didn't just keep them in their cages.

He actually took them out, took them for walks. That's difficult to do with the rhesus monkeys because they're difficult to tame. But he was able to do that for some of them. And he found out that in that more natural situation, it looked like they were showing some orienting. They didn't act like they were completely blind.

So he invented a way to test their orienting a little more formally and demonstrated using reaching movements that they could indeed localize stimuli in spite of the visual cortex lesion. And yet, they could not discriminate visual objects and patterns on the basis of pattern or shape. And those were the findings that opened up the possibility that maybe humans do have some vision after visual cortex damage also.

But before we look at humans, I want to talk about how such a monkey might be able to solve a shade discrimination problem. And I have to introduce Humphrey's concept of salience of stimuli for listening orienting movements. This is a diagram of his very simple testing apparatus.

He put this large circular piece of wood. It was painted white. It's about this big out in front of the monkey's cage.

And on that circular area where there were two little raised areas where he could put stimuli. He wanted them to be raised because he wanted the monkey to be able to feel it if he reached out. And on those two little raised areas that I've shown in the dashed lines there, he could put stimuli. So for example, he could put these little dark disks which he could vary in size.

So on one of his testing sequences, he put a 6-centimeter disk in one of the two positions. And he always used one, and he varied the position. He was rotating this thing around, so it didn't always appear in the same place in the field. And then, the second disk was varied in size.

And he taught them that if they would reach out when he brought that thing up and touch one of those, they would get a raisin or a peanut. And monkeys are eager to get such things. So they learned to reach. And he found out that they could reach accurately. They would reach directly for one of these.

So the question is, which one did they reach for? And this is one of his graphs where he's put the variable sized disk on the abscissa here, and he puts the number of times they choose that one. And you can see if they were both 6 centimeters, they performed a chance level, as you would expect. But otherwise, they were always choosing the larger one.

And he commented that studies of frogs, who we know use the optic tectum as their main visual system structure, will do the same thing. They'll respond selectively to the larger of two stimuli until it gets above a certain size, and then the frog changes its behavior, and it starts acting like it's dangerous, acts like it's a predator.

So he defined, then, the relative salience of these two stimuli in terms of the reaching movements. If they reach more to the larger one, then that was the more salient stimulus. So he knew size of the disk was an important property for eliciting orienting movements.

So then he tried other things. So for example, he had a red disk and a little horizontal black bar. And he found out that with using that pair, the monkeys reached 65% of the time to the red disk and only 35% to the bar.

So then, he tried this pair. They look just as different to us, a plus sign and a circle. And he found out that the monkey reached about the same to the two of them-- 52% to the plus sign, 48% to the disk-- probably not significantly different.

And he did a number of pairs of stimuli like this. So he knew, then, which stimuli were more salient to the monkey. Then once he had these results, then he continued to present the pair of stimuli, one of these pairs. And now, he would reward them only if they touched one of them and not the other. So he was now not just looking at preferences, he was looking at learning to go to one or the other.

And what he found was that in the case of this first pair, the monkey could learn to choose either the red disk or the horizontal bar. He could be trained to reach even to the less preferred one. But in the case of this pair that were almost equal in their salience and the reaching tests, the preference tests, he couldn't train them. They couldn't learn to reach always to one and not the other.

The reason was not due to the red color here because he could use the red color. He could have one red and one black. But if they were equal in salience or nearly equal, then they couldn't discriminate. And he did a number of pairs that indicated to him that, at least at this stage in the recovery of these monkeys, they were using the salience for listening-orienting movements as a basis for discrimination.

So this is what he said. He has a kind of shape discrimination it doesn't mean that the monkey sees the shapes like a normal monkey. He fails when the shapes have nearly equal salience for eliciting orienting movements, even if they look very different to us.

And I've spelled out his interpretation as clearly as I can here. He can learn to reach always for one of two stimuli when one of them attracts his or her orienting movements more than the other one. He can learn to go to the less preferred one or the more preferred one.

So the monkey apparently has the ability to monitor his own orienting preferences. And I just want to point out that, perhaps, the less-- maybe you have to be pretty smart to be able to do that. Monkeys are pretty smart. Maybe that's why.

So maybe humans with striate cortex lesions could do something similar. And maybe with practice, at least some people could become more aware. Now, why do I say that? Well, you'll understand why I'm saying that if we review now humans with so-called cortical blindness. These are people that have lesions of the visual cortex producing a blind area or scotoma, [? pluralist ?] [? scotomata ?] in their visual field.

So for example, if you have a lesion of all or the striate cortex in the left hemisphere, you will have a large scotoma covering the everything in your visual field to the right of the fixation point. So you'll have only half the visual field that you have normal vision. If you have a partial-- let's say, just the upper part of the visual cortex on one side, you would be missing just the lower quadrant of the opposite visual field.

And that would be true for left and right eye because of the way the fibers cross at the optic chiasm. Everything in our right visual field-- not the field of the right eye-- but the right visual field to the right of the fixation will go to your left hemisphere, left striate cortex. And similarly, the left goes to the right visual cortex.

So the question, then, for the humans was, is there any vision in areas of the visual field where the person says, I see nothing? Because that didn't change. The early people that studied this were completely correct. If you show people patterns of any sort in that blind area, the scotomatous area, they say they don't see anything. I see nothing.

But if you ignore the verbal responses, you can get orienting movements. And that was seen. We basically had to monkey-fy the test. Monkeys can't talk either, so we have other ways of testing them. Well, that's what we had to do with humans.

It was done first at MIT here by Richard Held and his students. He used eye movements, measured eye movements. And when a little sound occurred, he said, when the sound occurs, there's a stimulus. I want you to move your eyes to it. And they say, but I can't see any stimulus. He said, move your eyes anyway. Just guess. Make a choice. And he found that they could do it.

I remember, Dick and I used to talk a lot in the hallways. And I told him that hamsters are people, so you ought to be able to get people to do the same things hamsters can do. And he did.

In England, Weiskrantz and his students used the kind of reaching movements that they had used with the monkeys. And they found and it was easier, actually, to study using reaching movements. They also showed that people can, in a cortically blind area, they can reach fairly accurately.

And Weiskrantz then coined this term blindsight. It's just a one-word description of what these people are like. You show them something. They say they can't see anything there.

And yet, they can reach. They can orient to it. So yes, they're blind, and but, yes, they also can see something.

So why did it take so long for these things to be discovered? It was discovered only after the hamster experiments here at MIT. I think there's two factors. One is behavior can sometimes depend on brain mechanisms that are isolated from the verbal system.

We tend to rely on what a person says when we test humans. If they say they can't see, we believe them. But remember, when you're talking to someone, you're talking to part of his left hemisphere. That's the verbal system.

He's got a lot of brain that you're not talking to that are controlling his movements. And that's a major concept in neuropsychology that I want you to pay attention through here. And that's what' the phenomenon of blindsight shows, one of the things it shows.

But there's also-- when you make large lesions of the cortex, you're also going to have to deal with diaschisis effects. Quantitative factors are very important. And I want to go through some of that evidence. First of all, if you do striate cortex lesions like we've been discussing with hamsters, and monkeys, and people, if you do them in a tree shrew, a squirrel, or a cat, or in a baby hamster-- let's just talk about the tree shrews and squirrels initially-- they show us sparing of pattern and shape discrimination abilities.

They may not be completely normal. But without striate cortex, a squirrel, or a tree shrew, an animal with a very large midbrain tectum can discriminate upside from down and upright-side-up triangles. He can discriminate horizontal and vertical stripes and other kinds of shapes and patterns.

Similar studies were done of the cat at the University of Pennsylvania by Jim Sprague and his collaborators. And he showed some sparing of pattern vision. It wasn't nearly as good as in the squirrels and tree shrews, but they weren't as bad as monkeys and even rats. So what is going on?

Well, Sprague was an anatomist. And he knew that there was anatomical evidence, also some electrophysiological evidence for multiple parallel ascending pathways that carry information to the neocortex. So let's just look at that here.

This just shows in red the optic tract. This is the picture I showed you before-- optic tract and the accessory optic tract fibers. There's one little bundle of fibers coming from the retina.

Now, here's the geniculate body, and here's a cell in the geniculate body getting input. Those axons go up to the striate cortex. But now, axons are coming there to the colliculus too.

There are neurons there in the colliculus, like this one, that have a projection into the thalamus. They don't go from colliculus to the cortex. They go into the thalamus.

They project to neurons in the thalamus. They project to neurons in the thalamus that project up to the cortex. They go to areas mainly outside the striate cortex.

So there's another route, then, to get from the retina to the cortex by way of the colliculus. Now, it turns out, there's also a route through the pretectal area, which receives direct connections to the retina. That also has a connection through an adjacent part of the thalamus very much like the green pathway, as shown there, that also goes to cortex.

Physiological studies had shown that there's-- in the cat-- that there's at least four. Three of them, we knew anatomically. The fourth one, we're less certain about. It may involve this central part of the lateral geniculate body here, but that's not certain. We're going to focus on the ones we know anatomically.

So we're assuming, then, that those pathways are the ones that allow an animal like a tree shrew or a squirrel to discriminate patterns. So that was tested in laboratories in North Carolina, primarily-- people at Duke University. And they found that, indeed, a tree shrew or a squirrel started failing these pattern and shape discriminations if you eliminate the projection area of this region of the thalamus that gets input from the optic tectum.

There were also studies of the cat and the hamster-- and she studies were done here, the cat studies were done a couple of different places-- that showed if you made the lesions very early in life, they had better pattern vision than if you did the lesions later. And there was evidence that that sparing of function also depended on these additional pathways to the cortex.

Now, let's talk about the diaschisis effect that will show also the importance of quantitative factors. The first studies I talked about just showed that animals with a very large tectum pathway, other than the geniculo-striate pathway are sizable enough they can do some pattern and shape discriminations without the geniculo-striate system. This is a different kind of study. This only concerns orienting movements.

Jim Sprague was making unilateral lesions of the cat. He tried just taking out the striate cortex on one side, for example. And he found that after he did that, they lost their orienting in the opposite visual field.

So if he did the right striate cortex, the field to the left of the animal, he lost his orienting movements altogether. But if he waited a while, they came back. They recovered.

I noticed the same things in hamsters. The hamsters recovered a little faster than the cat. The cat has a larger cortex. OK, if he enlarged the lesion, they took longer to recover.

Then he found-- he kept enlarging it-- if he enlarged it, made it very large, so it included auditory and some other sensory areas as well as the visual areas, the orienting to visual stimuli never came back. He could get a permanent hemianopia in those tests of vision in one visual field after large unilateral ablations. So what is going on? Why would a lesion of the auditory instrument of sensory areas added to the visual cortex produce a greater visual problem? Does that make any sense? It does make sense if you think of the diaschisis effects.

Let's go through the anatomy. What I'm showing here is this diagrammatically. I'm showing cortex on the right and left sides. We know that each-- the cortex on the right projects to the right superior colliculus. This is an outline of the upper part of the midbrain tectum.

The tectal superficial layers we know receive retinal projections, but they also get projections from the cortex. Those neurons in the upper layers project to deeper layers, which have some neurons that then project out to detect the spinal tract that we know is an important pathway and controlling head and eye movements or anti movements. There's also some crossed pathways that go across the midline, where one tectum inhibits the opposite tectum. This was all known to Jim Sprague.

He also had noted that not only the visual cortex projects to the superior colliculus, but also, the auditory cortex projects to the colliculus-- also, the somatosensory cortex. Now, those other cortical areas project somewhat deeper. They project into these intermediate layers of the tectum. The point was, though, they project to the tectum.

So the larger he made his cortical lesion, the more input he was removing from the tectum. So his reasoning was, OK, if I remove so much excitatory input to the colliculus on one side, eventually, maybe, the colliculus simply will not respond anymore to the visual input from the retina. See, he's got a pathway that should be able to control orienting movements-- retina to superior colliculus in the opposite side, and then the output of the tectum, output of the colliculus. He should be able to orient. And yet, he loses it.

Maybe it's a diaschisis effect. He's depressing the tectum by removing so much cortex. Well, how do you test that? He came up with a brilliant idea.

Let's just ablate the opposite tectum here, get rid of some of these crossed inhibitory pathways. Maybe that tectum will recover its responsiveness. And that's what he did.

So first, he's doing lesion 1 there. That's the lesion, remember, that he had to make very large to include visual, auditory, and somatosensory areas, and then they lost their orientating. Then, after they were not recovering at all, then he ablated the opposite colliculus.

The result was that, right away, the animal started responding again with orienting movements in the formerly blind field. I found that so interesting and such a very nice demonstration of diaschisis effects, which were generally being ignored by people because they didn't use anatomy together with their physiology and behavioral knowledge enough that I called it the Sprague effect. And that's generally what it's referred to today.

Now, I don't think the effect is only due to the removal of the inhibition to the opposite side because you have similar kinds of crossed inhibition at lower levels in the brainstem that control oriented movements as well. And when you remove that lesion, of course, you're also deafferenting some of those hindbrain mechanisms.

So are there any questions on the Sprague effect? Do you understand why it's a diaschisis phenomenon and what Sprague's test of it-- OK, two questions here.

AUDIENCE: [INAUDIBLE]

GERALD SCHNEIDER: He suddenly starts seeing in the formerly blind field. So first of all, what is the formerly blind field? Start here with just this lesion. That's all we'll do.

We're going to remove a large amount of cortex. He loses his orienting in the left visual field, which, through its retinal projections, projects to this tectum. Now, if you make lesions of the tectum, you lose those orienting movements, just like in the hamster.

So in here, you're removing cortex, and they lose the orienting movements but only when the lesion is very large. So your deafferenting the colliculus. That's lesion 1, as I show here.

So remember, now, that animal has lost orienting only in the left visual field from a large lesion in the right cortex. So when I say formerly blind field, I mean left visual field, the one made blind to any orienting movements, anyway, with lesion 1 here. So then, he makes a lesion in the opposite tectum here.

We know that that removes inhibitory pathways to the opposite tectum as well as removing all these descending pathways. Now, the animal, right after that lesion, starts orienting to things in the left visual field again. That's the formerly blind field. Now, he can orient there.

The tectum here has awakened with that lesion. That was the Sprague effect. Now, of course, you say, well, what about his other visual field? He's done this tectal lesion. And yeah, he lost orienting in the right visual field. I don't think the cat's any better off, but it was a test of diaschisis, you see.

AUDIENCE: [INAUDIBLE]

GERALD SCHNEIDER: Yes, Sprague had studied the anatomy. He was an anatomist as well as a neurologist. And he had studied these path-- he had done extensive studies of both the cortical projections to the tectum and the intratectal connections, retinal projections. He was a good anatomist.

Now, there are a few-- not very many phenomena in neurology that are similar to this-- not very many. Yes?

AUDIENCE: [INAUDIBLE]

GERALD SCHNEIDER: No, it's not a compression. Cells are simply depressed in their function. They're there in the right tectum. They're getting input from the retina, but they're not responding.

The input is not reaching the output pathways because the cells are simply not reaching their threshold for firing action potentials. But they start doing that as soon as he removes some inhibition. There was another question.

AUDIENCE: [INAUDIBLE]

GERALD SCHNEIDER: Almost immediately after the tectal lesion, they start responding. I mean, he will wait-- you mean after the first lesion? No, he did the cortical lesions first and proved that they were unresponsive, waited a long time.

Now, in fact, you can do this kind of experiment with simultaneous lesions too. I tried this in the hamster, and here's the difference. If I make an equivalent lesion in the hamster, I remove visual cortex, he loses orienting for a week or less. If I enlarge it to include auditory, somatosensory, he just takes a few weeks.

So I tried removing the entire hemisphere on one side. The animal still recovered his orienting, but he took longer. You see, there's a big difference in relative quantity of input to the tectum in the hamster and the cat. The hamster tectum is relatively much larger than in the cat compared to the cortex. Or maybe a better way to say it is, the cortex is a lot smaller.

In relative terms, the tectum is large in the hamster, but the cortex is relatively much smaller and compared to the brainstem. So the species differences you see are quantitative differences. And you have to understand diaschisis effects to appreciate these things. It doesn't mean that the hamster has-- his cortex is doing-- his brainstem is doing so much more. It can just recover better from a cortical lesion-- less diaschisis because less input coming from the cortex.

Now, let's try to briefly go to one more topic here today, the role of extrastriate cortex in the monkey. And that started with studies by Kluver and Bucy, who tried removing the whole temporal lobe. At the time they did that, all of the anatomy of the visual projections into extrastriate areas, including temporal cortex, had not been worked out.

Here's what they got. They got pretty drastically altered monkeys. And these are monkeys are often pictured in textbooks of brain behavior. The monkeys became tamer.

Rhesus monkeys are very difficult to work with. They're pretty wild. They become suddenly became very docile. They were hyper aural.

Everything, like a baby, they would grab and put in their mouth. They were hypersexual. Famous pictures of one monkey mounting another monkey was mounting another monkey is mounting another monkey, showing their hypersexuality.

They also had altered eating preferences. They changed their tastes. They also had vision problems. At first, those weren't well defined.

In fact, it was thought that maybe they stick everything in their mouth because they can't identify them readily. So then, people began interested in separating out these different effects. After all, they had removed the entire temporal lobe, which meant neocortex of the temporal lobe, the amygdala, and hippocampus-- so parts of limbic system as well as parts of neocortex.

And, as you might expect, the limbic system components were responsible for some of these things, and the neocortical components responsible for others. Limbic system effects, especially the amygdala, resulted in the tameness, hypersexuality, hyper aurality, altered eating preferences. But the visual effects were due to neocortical lesions.

The inferior part in the lower part of the temporal lobe neocortex is known to get visual inputs, primarily transcortical inputs, from the juxtastriate areas of the visual system. Now, we know that there's many representations of the retina in that large area of cortex in front of the striate cortex.

If you make just inferotemporal cortex lesions, there's only visual effects. There's no scotoma, no blind area. They orient everywhere. And you impair only the more difficult pattern and shape discrimination. So they can still do the simple ones. But as soon as you get the problems that are harder for a normal animal, then you have difficulty. All right.