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Anatomy and Physiology of the Vestibular System

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Doctor Kelly is an Associate professor of Physical Therapy at Quinnipiac University. She has taught in the areas of neurologic rehabilitation, balance falls and vestibular dysfunction for 17 years. She received her Bachelor's in Physical Therapy from the University of Connecticut, her Master's in Neurology from Boston University, and her doctorate in education from the University of Sarasota. She is also a board certified Neurological clinical specialist. In 2004, Dr. Kelly completed her 200 hour certification in Kripalu Yoga and in 2008 she completed an additional 200 hour training in Anusara Yoga.

Dr. Kelly's passion for both yoga and preventing falls in older adults has created many avenues of service. She has presented her work in the areas of yoga for fall prevention and electromyography and Yoga asana both locally and nationally. Dr. Kelly has presented many courses on our Physical Therapy.com affiliate site and we were so thrilled when she accepted our invitation to present this course on audiology online. Dr. Kelly, at this time I'll turn things over to you.

Thank you Carolyn. Thanks for the intro and hello to everyone. Nice to see you. Well, I don't see you, but nice to see so many people logged in for this. The anatomy piece of the vestibular information that I present is actually one of my favorite pieces to do.

So I'm very excited and as, as Carolyn said, I do have some planned question slides where we'll just stop and take a break if you need to ask questions. But if you have a question as we're going, just type it in and I'll do my best to get to it. And I apologize if the Chihuahua gets a little fussy. He wouldn't stay outside the door where he belongs. He was cracking and whining.

So here he is on my lap, which is where he usually sits when I'm working, which is not very effective. But here we go. We're trying. So the first thing I'll do. Oops.

Here we go. We'll start just by reading the learning objectives. So it's on the audio. So after this course, learners will be able to identify the main components of anatomy of the vestibular system. Describe the basic physiology of the vestibular hair cells and the push pull mechanism of the vestibular system.

Identify the main ascending and descending targets for afferent vestibular data and describe the function as related to balance and or dizziness of each target. Identify the efferent tracts that arise from the vestibular system. Describe the function of the VOR and its relationship to both Visual and vestibular. And. And for those of you who still have bad memories of learning ascending and descending tracks from undergrad notices, just identify.

We're not going to go crazy. I think it's important to understand where the information is going to and how people need to use it. But really the gist of the presentation is to get a really good sense of the anatomy and then to start to delve into the physiology, but not as deeply as the anatomy. This is an artist rendition of the inner ear that. I like this cartoon because it gives you a nice sense of where the structure is, right, you see the cochlea and the semicircular canals, but it is just a cartoon.

So just a couple of sort of background pieces of data. Vestibular problems that people may. Problems that people may complain of that could involve vestibular pathology include dizziness and vertigo, imbalance, visual fatigue or visual blurring, and of course, headache. And I'm sure many of you know that differential diagnosis of headache is extremely difficult. So it's always important to take a full past medical history.

And I would never blame the vestibular system first for a headache because that's, that's not the main issue. The main issue is dizziness and vertigo. And the true definition of vertigo, right, if you go into the dictionary, is I am spinning. And not all people say this to you. A lot of people say dizziness, which is one of those sort of generalized terms like I have low back pain or, you know, I don't feel well, spin.

So dizziness could be from almost any system, not just vestibular vertigo. I am spinning, I am turning around is generally indicative of vestibular dysfunction. So just a couple hints when you're taking history. And why is this topic important? 8 million primary care visits annually and it's the number one reason for someone over 65 to consult their physician.

Unless you read the low back literature, then low back pain is the number one reason. So it depends on who you read. I read vestibular literature, so I say it's vestibular. It's second only to headache and prevalence. And almost half of the population.

Right. 42% will complain of dizziness at least once in their lifetime. So it's a huge problem in this country. And it's estimated that about 85% of all dizziness is peripheral. And that is significant because peripheral dizziness is the easiest to treat, either for audiologists, physical therapists, occupational therapists, we can all provide treatment that can impact dizziness in a positive way.

So when we Find out that it's peripheral. We know mostly what to do from the literature and we can be very, very successful. So that's why this topic is important to me, because it affects a lot of people and we can have a positive impact in a short amount of time.

So the purpose of the system is to mainly detect angular velocity and linear acceleration. And I don't usually make a huge deal out of the difference between velocity and acceleration when I teach this to my entry level students. But for those of you who are clinicians, you're out there, you're hearing people, you're taking history. This is super important. One piece of vestibular system is a velocity detector.

One piece is an accelerometer. So it's two different structures and you'll get two different complaints from patients. So it's important to know which structure. And we're going to get into that. And one of my favorite books for pts is L. Sullivan.

And there's mistakes in that book, so I always bring that up because you may run across articles or books with mistakes. It's angular velocity, linear acceleration, and the vestibular system is how we perceive gravity. It's really the only way we can understand gravity is with the vestibular complex.

So with this information. Excuse me. The vestibular system first stabilizes the gaze, so it keeps visual images on the fovea. And it does this with what's called the vor, vestibular ocular reflex, which we'll talk about later. And in vestibular pathology, it's one one way we assess the integrity of the vestibular system by looking at the vor.

The vestibular system also controls posture, so it keeps the body balanced, especially when the head is moving. It does that through the descending tracts, the medial and lateral vestibulospinal tracts. It provides information for spatial orientation. So, so it takes information from gravity and position of the head and allows us to orient ourselves in space so we can coordinate the head and body movements. And, you know, those of you who study pediatrics, you know, righting reactions develop first in the body, then in the head.

And then part of our postural control system is to keep the head aligned over the trunk, right? We keep the head aligned over the trunk. And how we do that is with vestibular data. So I have a question here. Does vestibular system detect angular acceleration or angular velocity?

So it's like the slide says, it's angular velocity, linear acceleration, not angular acceleration. And it's because of the structures that do the work. And I'm going to go over the structures as we move along. So that should become very clear.

So the vestibular system works in conjunction with visual data and somatosensory data. So when we are maintaining upright, when we are working on postural control, we use input from the vestibular system, the visual system, and the somatosensory. So we use this peripheral afferent data to keep the eyes steady in the head and to keep the trunk upright to maintain posture. And some of this is processed centrally. The vestibular data is mostly processed in the brain stem and in the cerebellum.

Visual data, you know, is going to ascend to the cortex, but there's not much vestibular data that A sends to the cortex. So we take these three pieces of sensory data together to help maintain upright posture and to keep the eyes steady. So the vestibular system has to work with all three systems because we need all three pieces of data for accurate postural control.

So. So when I teach the anatomy, I break it up into three sections. It's sort of artificial sections because obviously they're all connected, but I think it makes it easier to understand. So we'll talk first about the peripheral sensory apparatus, then about the central processor, and then about the tracks, right? So we start in the periphery and we move our way in and up.

And for me, it just makes it easier to teach. But obviously, they're all. They all have to work together. They're all connected.

So when we look at the anatomy of the ear, you have the external ear. You have what's known as the inner ear, which is really what we're talking about today is the inner ear, the vestibular nerve, and central processing. So hopefully. I thought that was a picture. I'll come back to this slide.

So here's your external, right? And here's your inner ear in that way.

So to look at the external anatomy very quickly, just to orient us all, you have your external canal, tympanic membrane, the middle ear, the oval window, and the inner ear. And all the structures are extended. The external canal are enclosed within the temporal bone. So I like this artist's rendition of the system because you can actually see the temporal bone here. You see, this is, you know, inside the bone.

So the artist is really giving you this sense that the vestibular apparatus is embedded in bone. And, you know, why is this important? Well, it's important if someone gets a fracture to their temporal bone, they're going to have vestibular dysfunct so obviously, here's an ear, right here's the external canal, which is where, you know, stick your Q tip, even though you're not supposed to, and the doctor has told you not to since you were five, you do it anyway. And then the gateway between the outer and the middle is the tympanic membrane right here. So what you have in here is known as the middle earth.

And since you're all audiologists, I'm assuming you're very familiar with the bones of the middle ear, the incus, the males, and the malleus and the stapes. And what's important for today about these bones is really the stapes articulates with the oval window. So it's very hard to see in this picture. We're going to have a better picture in a second. But it's the stapes that is covering the gateway, the oval window between the middle ear, which is here, and the inner ear, which is really what we're talking about today.

And you recognize this middle ear with the eustachian tube that drains into the nasal pharynx here and in here. If fluid collects, this is when you get an ear infection. And the physician will look at the tympanic membrane and sees it's very, very pink. And that's how we know that our children have an ear infection. Past the oval window is what we have what is known as the inner ear, which contains the vestibular structures that we're talking about today.

This is a slightly different rendition, not as fancy, but you can still see the separation between external, middle, and then the inner ear. The bone has been more sort of excised away. So you can now see the vestibular nerve. And you see the superior and the inferior portions of the vestibular nerve that come together to form the vestibulocochlear nerve, which we'll talk a little bit more about later. I have a question here.

What is the difference between acceleration and velocity, other than the fact that different structures are responsible? Well, velocity is. And acceleration is rate of change of speed. Right. So velocity would be measured in meters per second.

Acceleration would be measured in meters per second squared. So you only perceive acceleration when there's a change in the speed, whereas you can perceive velocity all the time.

All right, so I'm going to keep going here. All right, so this is really why we're here today to talk about the inner ear. And the inner ear. You can look at in really two sections. You have the section where.

There where the cochlea is, and you have the section where the vestibular structures are. And in the middle you have what's called the central chamber or the vestibule. So you have three semicircular canals per side, right? You have an anterior, posterior and lateral on each side. You have two otoliths on each side, a utricle and a saccule.

Then you have the vestibule, the central chamber, and you have the one cochlea on one side.

Let's see. This should be a picture next. All right, so this is probably the most used, most famous vestibular picture ever. I forget the source it comes from, but everyone uses it because it's a really nice rendition. The structures.

So what you see is the artist has excised the structures completely out of the bone. So this whole structure used to be surrounded by the temporal bone. Now the artist excised it out for us so we could look at it. So here you have the three semicircular canals. You have anterior, posterior, lateral.

Here you have the vestibule right in the center. And you see that the artist has excised the top of the bone of the vestibule. So we could see inside. And you see the utricle and the saccule and then the scala tympani, which is the line of demarcation between the vestibule and the cochlea. Right.

So you know that the cochlea is going to share endolymph and perilymph with the rest of the vestibular structures, right? So the fluid dynamics is all shared. So if I just go back one minute, here you have the three canals on each side, two otoliths, utricle and saccule, and just one cochlea per side.

So the central chamber is filled with perilymphatic fluid. And. Excuse me, what we have in pario lymphatic fluid is this ratio of high sodium to potassium, which is similar to csf. And, you know, why do we kind of care about that? Because it's not the only fluid hanging out in there.

So we have perilymph, and it communicates via the cochlear aqueduct with the cerebral spinal fluid in the subarachnoid space.

Sorry, I thought the next slide was about endolymph, but it's not. So we have the three canals, and I just want you to notice I gave you anterior, posterior and lateral. Each of the canals has two names. So depending on who you read, depending on the anatomist who's done the drawing, the anterior canal is also known as the superior canal, posterior Canal is. I've rarely heard it called this, but it can be known as inferior, horizontal or lateral.

A lot of people use these interchangeably. So in general, the anterior canal is going to detect sagittal plane motion. So nodding right up and down like that, sagittal plane posterior canal is going to connect, detect frontal plane motion, which is side bending.

Horizontal canal is going to detect transverse plane motion, which is rotation. Now, in reality, any movement you make tends to stimulate at least two, usually all three canals. So this is sort of for a teaching point, but in reality, you never really just stimulate one canal. And then at the end of each canal is a structure called the ampulla. And all three of the ampulla articulate with the utricle.

So this should be the same picture. Nope, sorry. All right, let me go back to my picture. I apologize. So here's the anterior canal, posterior canal, lateral canal.

And you see this widening at the end of each canal that's known as the ampulla. And all three of the ampulla articulate in the same direction on the same structure, which is the utricle. And the ampulla is an extremely important structure because it's going to contain the sensory structures of the semicircular canals. And these are the structures that are going to detect linear or, sorry, cancel angular velocity. The canals.

Right, angular velocity.

So the semicircular canals have a kind of a tube within a tube sort of anatomy. There's a bony labyrinth on the outside, and then on the inside, suspended is the membranous labyrinth. And then, like I said, the ampulla is at the base of each canal. So you have the bone protecting this membranous structure, and it's suspended by fluid and connective tissue. So the membranous labyrinth is going to be surrounded by perilymph, which has that high sodium to potassium ratio, but it's going to be filled with endolymph, which is the exact opposite.

Right. Notice it's high potassium and lower sodium. So the significance of this is if these two fluids interact, the perilymph and the endolymph, what you get is severe, constant chronic dizziness. Right. We don't want these fluids mixing.

How does that happen? It happens if there's a hole or what's known as a fistula. So some of you may have come across that. Especially, you know, if you do a lot of ear testing and eng testing, you may have come across patients with fistula and they have severe, constant dizziness. It's because the perilymph and the endolymph are mixing, and they're not supposed to.

The endolymph is absorbed by the endolymphatic sac. And the membranous labyrinth is going to contain what's called the cupula, the crista ampullaris, and the cupula, which is the sensory organ of the semicircular canals. So you have your three canals, anterior, posterior, lateral. You have your membranous labyrinth. You see, the artist has so nicely excised away part of the bony labyrinth for us, left us to see the membranous labyrinth and the widening here, which is the ampulla.

And then this is one of my favorite parts of this picture. It gives you this sense of the endolymph is in the center. Then there's a membrane, then there's the perilymph, then there's the bone. So this outside here is very delicate bone. And then it's all surrounded by the temporal bone.

Right. Thicker bone here you see the endolymphatic duct and the endolymphatic sac. That's how we overturn our endolymph. It gets absorbed in the subarachnoid space. And then if you look down here, it's a little tiny cochlear aqueduct.

That's how we turn over our perilymph. So all the fluid is shared between the cochlea, the vestibule, and the canals, endolymph and perilymph. And it gets turned over in two different ways. Endolymph through the endolymphatic sac, perilymph through the cochlear aqueduct.

And this is just a different resource I have for pictures. And this artist is giving you, really, the sense of the bone. Excuse me, the bone that's protecting the membranous labyrinth.

Excuse me. Because it's inside the membranous labyrinth that the endolymph is moving. And the endolymph is what moves the sensory organs. So we need to keep it protected so that it can be functional. So it's just a little different rendition.

So inside the membranous labyrinth is what's called the cupula. It's located in the ampulla. So that widening at the base of each semicircular canal is an ampulla. And it contains the cupula, which is this mass of gelatin. And it contains what's known as the crista ampullaris, which is the base of the cupula.

So how the system works is with really just fluid dynamics. You move your head and the endolymph Moves and it deflects what's known as the cupula. Inside the cupula are hair cells, and the hair cells are bipolar neurons that fire. And eventually an action potential is created on the eighth cranial nerve. So it's really just about fluid dynamics, right?

You move your head, you move the fluid, you move what's known as the cupula.

And what's interesting about these structures, let me. Nope, that's not where I want to be. Is if you take all the structures in this picture right here, all of this, it's going to fit right on top of a penny. That's how small they are. And they're located directly behind your iris, so embedded in the temporal bone, but directly behind your iris because vestibular data is intimately connected with eye movement.

So the system, the actual structures are at the same level as your eyes to keep control over them.

So you have three canals on each side. And the functions of the canal are to detect velocity. So anytime there's movement, right, Speed, velocity, it's the same thing. The horizontal canals work as a pair, and the anterior canal works with the posterior canal of the opposite side. So they work in concert, anterior and posterior on the two sides.

And what's interesting is the planes of the canals are not directly in line with the treatment planes, right? So they're closer to the planes of the extraocular muscles so that they can better control eye movement, keeping the eyes steady. So once the system detects movement of the head, right? So if you turn your head, you have velocity. The vestibular ocular reflex is going to generate an eye movement to keep the eyes steady.

So this next slide is showing you how the canals, they're 90 degrees to each other, right? There's one canal in each plane. They're not directly on the treatment planes. Slightly off from the treatment planes. The horizontal is about 30.

And honestly, different references say different things. I have three different references for treatment. One says 10, one says 20, one says 30. I don't know if there's anatomical differences or if we just don't know or if, you know, we've studied animals, and animals are different. I'm not sure.

Superior and posterior canals are about 45 degrees from the sagittal plane. So here you see, right. The sagittal plane would go down the center. But you notice that this canal here is not directly on the sagittal plane. It's a little bit.

A little bit off. So really, no matter what you do with your head, you can't help but stimulate one of the canals Most likely two of the canals.

And this is just another picture side view showing how the semicircular canals are not directly on the treatment plane, but you notice that they're 90 degrees from each other. So one in each plane slightly shifted.

Okay, so how. What is the function of the cupula? How do we actually go about detecting movement?

Well, you move your head, right. Turn the head, and you would move this fluid that's in the semicircular canal, the endolymph. And the fluid is going to move definitely the cupula. And if you look up here, it looks like the cupula kind of is a barrier in the ampulla, but it's actually going to let some of the fluid pass by. Some of the fluid will pass by.

And when the cupula deflects or moves, you move hair cells that are located inside the cupula. And again, these hair cells eventually make up the eighth cranial nerve.

So the cupula is a gelatinous mass located inside the ampulla. And the hair cells are what's known as the primary receptors of the system. So they extend from the primary afferent nerve of the vestibular system. They pierce the base of the crista ampullaris and go into the cupula, which. This should be a better picture.

Sorry, I'm going to go to the picture first and then come back. Here we go. So here's an ampulla, right. Blown up, of course, inside the ampulla is the cupula. You see, this is a mass of gelatin.

And then you have these columnar epithelial cells that make up the base. And you're going to notice from extending from the base are these hair cells.

Right. Each hair cell is connected to an afferent that's part of the eighth cranial nerve, the vestibular nerve. So this is actually one of my favorite pictures of the cupula because it's simple, but it's also very, very clear. Some of the 3D pictures, I find they get a little complicated, and it's very hard to understand the physiology when there's all these 3D things. So the most basic way to describe it is you move fluid, you deflect the hair cells, and eventually an action potential occurs on the eighth cranial nerve.

If we want to go a little deeper, there's two types of hair cells. There's phasic receptors and tonic receptors. So, Right. Tonic receptors fire all the time. Phasic receptors fire when they're moved.

When the hair cells are deflected towards the utricle, you get excitation when the hair cells are deflected away from the utricle, you get inhibition. So to me, these are some really cool hair cells because they're attached to bipolar nerves so they can fire no matter what direction. So if you think about that for a second, think about say a pacinian corpuscle in your hand and it either fires when there's pressure or it doesn't. These cells are so much more advanced because they fire if they're deflected in one direction, they fire an excitatory, if they fire in another direction, they fire an inhibitory. So it's a really highly evolved system to be able to do that.

So you see, movement of the head gives you movement of the endolymph, which gives you movement of the crista ampullaris, which is this whole sort of base, this whole thing here, the cupula, the hair cells, the base, this whole thing is known as the crista ampullaris. And it deflects, it's going to move kind of like a big balloon. And you see the hair cells are embedded the cupula, and they're going to move along with the cupula and cause a firing, either an excitation or an inhibition, depending on the direction of the movement. Alright, so if I turn my head to the right, my right anterior is going to fire an inhibition, so I don't keep going. My left posterior is going to fire in excitation, so they're going opposite directions.

So it can get really complicated to try and understand the movement of the hair cells. But I think it's really important because a couple of things. One, bad news. If you're over 30, your hair cells have already started to die. So sorry.

It's why the amusement park is not as much fun the older you get because you have less ability to perceive motion and spinning and it's more likely to make you sick. And then you know this already, I assume. But there's also the same type of hair cells in the cochlea that get destroyed with loud noises, right? So too much loud noise destroys hair cells, causes hearing loss, age destroys hair cells here and also in the cochlea. The other thing that destroys hair cells are aminoglyosides.

So antibiotics like vancomycin, anything with that myosin ending, it destroys these hair cells. And there's debate in the literature, do they grow back? Do the people habituate what happens? But you can have people with ototoxicity who have no vestibular function from overuse of these broad based antibiotics. So I just think they're really important for us all to understand and respect.

And, you know, put some earplugs in the next time you go to that concert. So you save your hair cells. We should make a T shirt. Save our hair cells. This is one of the most simple pictures I've ever found of the cupula.

And I just find it really helpful because you can see that each hair cell, see there's a hair cell, is attached to a neuron, and then all these neurons are going to eventually bundle together to make the vestibular portion of the eighth cranial nerve. So, so just imagine if, say, this person was on antibiotics for a long time from, I don't know, some type of infection while they were in the hospital, and they lost half of their hair cells. And then you go to stand them up and they're unsteady, they're woozy. Well, they don't have the sensory structures that they need anymore. Right.

So it's very simple picture. You know, it's not giving you the whole whole idea. But I really like it because it really makes me respect how important these hair cells are. And you see this cupula is deflecting, and you could see how there could be a little bit of endolymph that might sneak by, right? Just a little bit.

It was explained to me in a course one time as more of a balloon where the fluid pushes, deflects, the cupula expands, and most of the fluid bounces back, and you get just a little bit sort of sneaking by. And why does that matter? Well, when you're dehydrated, the endolymph gets thicker, gets more viscous. Right. So you have a harder time using your vestibular system if you're dehydrated.

The viscosity of the endolymph is very important. It's very closely regulated by the body.

And then this is really like a microscopic view of the hair cells. So if I go back to here, you can see there's a taller hair cell and then these little ones like a pointer finger. So the tallest one is called the kinocilium, and then the rest are called stereocilia.

And when the cupula deflects the hairs towards the kinocilium, it means it's going towards the utricle. So you get excitation. When it goes away, it's going away from the utricle, you get inhibition. And then you see in this picture the type one, the type two. So this type two is firing at a low level all the time, Right.

It's how You. It's part of why you know where your head is in space, because it fires all the time. This type two, you see, it has a little wider base, little fatter guy here. It needs a little more support because it's only going to fire when it's moving. So that's just a blow up of the hair cells.

All right, so I'm just going to stop here and ask for questions before we move on to the otolith, because I want to make sure everyone's clear. Right. Three canals on each side, an ampulla at the base of each canal, a cupula inside each ampulla. You move your head, you move the endolymph, and then you move the cupula, which gives you eventually an action potential. And we're going to talk a little more about the nerve, the vestibulococcle.

Cochlear nerve. Blah. In a minute. But I just want to make sure that the anatomy is all clear.

Let's see. Is the anterior canal sometimes known as the superior canal? Yes. Yes, it is.

Oh, I see. Caitlin is typing. Someone's typing. If you have questions, please type them in the Q and A box. Yes.

So anterior is sometimes called superior, posterior is sometimes called inferior. Horizontal is sometimes called lateral. And then.

Sorry, you have that. If you download the PDF, it's right on the slide, so you could always refer back to that. So what is meant by the plane of treatment? So the plane of treatment refers to the planes of the body, right? So you have the sagittal plane, which goes down the center.

You have the frontal plane, which cuts the body front to back, and you have the transverse plane, which would go this way. So instead of being directly aligned in the planes of treatment, like here, the anterior canal is about 45 degrees off. So it's like that. It's not that big of a deal until you get into treating eye and head movements for. Let's see.

I'm having a little. Can I open this box, please? Bigger. Caitlin. For athletes that may experience more motion, ice skaters, is there more wear and tear, which causes more damage?

That's an interesting question. So for athletes that may experience more motion, like an ice skater, is there more wear and tear, which causes more damage? There's no evidence of that. More damage. What we think.

And it would really require a study. So if you know, any ice skaters that want to do a study, have them call me. But what we think is that their vor, the vestibular ocular reflex, is just so much more tuned in than the average layperson because Most people, if you spin like they spin, will get dizzy. Obviously, they're not getting dizzy because they go on and keep skating. So the theory is that their VOR is sort of more in tune.

It's a stronger reflex, but we don't really know. We tend not to study the healthy ones so much. All right, so I'm going to keep going. And the next section is to look at the otoliths. So you have three semicircular canals on each side, so you have a total of six.

You have two otoliths on each side, so you have a total of four. The utricle is the larger structure. It's located in the transverse plane, which is this one here. Right. It's gonna chop me in half.

And all three canals originate and terminate on the utricle. So when you're looking at the anatomy, the canals articulate with the utricle, not the saccule. So when the head is horizontal, which means I'm sitting upright right now, the sensory organ of the utricle, which we'll talk about in a second, is nearly horizontal. So it's almost here. Right about here.

Right. So flat, horizontal would be here. Let me get my thumb out of there. It's just about like this. So the sensory organ that's inside that structure is sort of hanging out like this.

The saccule is smaller. It's located in the sagittal plane, which would be this plane. Now, this is quite a perceptual test. Have you guys ever tried looking in the webcam and lining up on the treatment planes? I think I'm going to put this on the quiz next time.

Here's the sagittal. It's more distal from the canals. And when the head is horizontal, the saccule is nearly vertical. So it's here. So these two structures are sensitive to gravity.

Right. So their tonic cells are always firing when they perceive gravity. If you're on Earth, you always have gravity, which means they're always firing. So you have a structure that's here, and you have another structure that's here, slightly down. And they're telling you all the time that gravity is coming from the center of your head down towards.

For me, I'm sitting, right? So down towards my seat. If I were standing, gravity be coming down from my head towards in between my feet, and that's the center of gravity. And how do I know that? I know that from my utricle and my saccule.

They're also sensitive to acceleration. So change in speed. Change in speed, Right. So speed is meters. Per second.

Acceleration is meters per second squared, so rate of change of speed. So you only perceive movement from the utricle and the saccule when you're changing speed. It's why, if you're, say, if you're going on a really long elevator ride, like 30 floors, you feel at the first five, and then the velocity of the elevator stabilizes and you don't feel like you're moving anymore because you're not accelerating, you're at a steady speed. Then you get that sort of stomach in your throat feeling when it stops, because you're decelerating, you're slowing down. So your utricle and your saccule are telling you, oh, we're slowing down.

Oops, we're speeding up. If you're going at a steady speed, they don't. They don't fire. The phasic receptors don't fire. Only the tonic receptors fire because you have to know where gravity is, right?

So you have two otoliths per side utricle, which is the larger saccule, which is the smaller. Here's my famous picture again. When I teach this on ground, I just hand this out on a big eight and a half by 11 piece of paper. So they have it next to. To their computers.

So if you could. If you can print it out and make it bigger, it's really helpful to look at the anatomy. So here's my utricle. It's bigger. You see all three canals articulating on the utricle.

Here's my saccule. It's smaller, it's closer to the cochlea. And then you see that they're connected by what's known as the vestibular aqueduct, this little teeny tiny thing right there. And that's connected to the endolymphatic duct, which is connected to the endolymphatic sac, which drains into the subarachnoid space, right? So all the fluid is connected.

And this endolymph, I'm just going to show you here, I don't. I don't usually go into this because I don't know that much about it, so don't ask me any questions. But you see the ductus, what's it called? Neurians. And it's going to connect right here to the cochlea, see?

So all this endolymph is shared, right? So the first thing you might think if someone comes to you with tinnitus is, what's happening? Are you dehydrated? Because if the viscosity increases in the endolymph The. Then the hair cells of the cochlea aren't moving smoothly.

Right. So we always ask our older patients, you know, have you had enough to drink today? Are you drinking water? You know, a lot of them avoid water at night so they don't have to get up to pee. And then they wake up in the morning and they're lightheaded.

It's not from anything wrong with the structures, per se. It's because they drained all the water out of the structures. All right, so you have three canals, two otoliths. Each canal articulates on the utricle, which is bigger, and all the structures share endolymph and also perilymph. So in here, see, that's the vestibule in there, that's all bathed in perilymph.

And that's also going to be all through the canals and into the cochlea. Why? You know, hearing problems and vestibular problems go together because they share fluoride fluid and they share innervation. And then they share anatomy to get their data from here up to the central system, they share all their anatomy.

All right, so the macula is the sensory organ of the utricle and the saccule. So you have the cupula, which is the sensory organ of the semicircular canal. So, so you have three canals, each end in an ampulla. Each ampulla contains a cupula. That's the sensory organ.

The macula functions similarly to the cupula for the utricle and the saccule. So the anatomists had mercy on us, although the test is not too hard, so no worries. But it's just called the macula of the saccule and the macula of the utricle. I like it when they do that. Right.

It's easy to remember.

So a macula is a thickened area of ectoderm, and it's going to contain the supporting cells and the hair cell receptors. And then it's going to have the otolithic membrane on the base and what's known as these carbonite crystals on the top. This should be. Here's my picture. So this is a very basic 2D picture.

It's pretty old, but I really like it because you can just see what's going on. So here's the base, here's the macula. You see more columnar epithelial cells here, supporting cells. You see a hair cell shooting out from each supporting cell. And then you have on top of the macula, what's known as the otolithic membrane.

And on Top of that, you have what are called oticonia. These are calcium carbonate crystals. They weigh the membrane down. And then look again. Just like with the cupula, each hair cell is innervated, right?

Each one.

And again, these hair cells can be damaged. They can be damaged by antibiotics. They can be damaged. Just natural aging. They die off.

So you can lose these hair cells. So the cilia of the hair cells are embedded in the otolithic membrane. That's the base. Each hair cell has a crystal on it. It's called the otoconia.

And the otoconia are important because as I'm sitting here, I'm sitting mostly still. The hair cells only respond to the pull of gravity, right? So as I'm sitting here, gravity is pulling on these oticonia, deflecting these hair cells ever so slightly. And that just tells me I'm sitting upright and gravity is going this way, right? If I go upside down, I practice this morning, so I was upside down for a second, my oticonia were telling me, dude, gravity's going towards your hands.

What is wrong with you? Right? So you're sitting here, you're working at your computer, you're doing whatever in the background. These hair cells are being deflected, and they're just telling you, right? They're telling you you are upright, you're here.

Gravity's coming this way. It's hugely important because it's the only structure we have that detects gravity, right? Your feet can tell you about pressure and that you're standing on them and that they're on the floor, and you can infer gravity from that. But actually detecting the pull of gravity, this is it right here, oticonia. Let me go back to this slide.

So again, linear acceleration or deceleration, also display displace the otolithic membrane. So it has to. Do you know, why doesn't it move? I apologize, why doesn't it move during. During velocity?

It has to do with the weight of the membrane, and the otoconia help weigh it down. So it needs a change in velocity to move it, right? Without the otoconia, it would move all the time, which is not what we want, right? We want a steady amount of information to tell us about gravity. So we can organize our postural responses around gravity, and we can organize our visual responses.

Your eye movement around gravity. And then when we change speed, that's good enough. I don't need it all the time because my semicircular canals are firing all the time. Telling me, is my head moving? Is anything Going on, what's happening.

So I don't. I don't need that redundant data. Here's a little fancier picture of the macula. So you see the 3D of the columnar epithelial, it's organized very similar to the cupula. So you have a kinocilium, a tall one there, and then the shorter, the little fingers.

And then you see how the otolithic membrane holds the. These calcium carbonate crystals. And this whole thing is gelatinous, right? So you have to move this gelatin to deflect the hair cells. And then here you have vestibular nerve axons.

It's telling you right there in the picture.

So it's the same as the semicircular canals. You move fluid, you deflect hair cells, you get an oxygen potential. The fluid that we're talking about is endolymph. That would be moving through the utricle or through the saccule, right? So I'm going up.

An elevator goes really fast at the beginning. It moves the endolymph that quickly deflects the macula, which tells me I'm accelerating in a linear fashion. You're going up, and then I get to the top, and it slows down really quickly. Same thing decelerating. And it only detects this change in velocity, this acceleration or deceleration, because this gelatinous matrix here is so thick.

And it's weighted down, right? It's weighted down. So it takes more than just a chain. It takes more than just speed. It takes a change in speed to move this.

Let's see. I think I can open. I have a question coming in. You stated that hair cells are always being deflected by gravity. Can you explain this a little more?

How are they being deflected without any head movement? Because gravity is pulling on them. Right? Gravity is pulling. Always constant.

That's a constant if you're on the Earth. So gravity's pulling on the otoconia right here, which are going to deflect, in my case, because I'm sitting up, they're going to deflect towards the floor. Going towards the floor, which is going to deflect that hair cell right there, all these hair cells, which causes an action potential on these nerves right here. So it's because gravity is a constant. If you took me off the Earth, right?

If you sent me to the Moon, I have no more gravity. It wouldn't be happening. It wouldn't be happening. But I can't get rid of gravity while I'm here on the Earth. So it's always pulling.

It's designed to respond to the pull of gravity.

All right, so this is a little more complicated. You have the receptors in the otoliths and the canals. Hair cells are located within both types of receptors. So I think it's really important just to understand the physiology of the system. The vestibular, the canals, the otoliths, and also the cochlea.

It's all based on movement of fluid and deflection of hair cells. And how does the fluid get moved? Well, in the case of the semicircular canals, the fluid gets moved by angular movement. Turn your head in an angular way. Right.

Angular movement. In the case of the otoliths, the fluid is moved by linear movement, but it has to be acceleration or deceleration. Right. I'm changing speed. So when you're on the T in Boston or if you take the subway in New York, when it speeds up and when it slows down, that's when you feel it the most.

That's your otoliths. How does the fluid get moved in the cochlea? From the sound wave. Right. The sound wave move.

This moves the tympanic membrane. The tympanic membrane moves the three bones of hearing. The three bones of hearing push on the stapes, which pushes on the oval window, which creates fluid movement. So the whole system is based on movement of fluid and movement of hair cells. All these hair cells start to die off in our 30s, and it gets worse when we're over 65.

It's part of the reason why our patients lose hearing and other ability to sense movement when they start to age. Because it's the natural part of the aging process. The hair cells die. The hair cells in the cochlea are destroyed with loud music. The hair cells in the otoliths can be destroyed by use of antibiotics.

Right. So we all have to think about where in the cycle our patients are and what's. What might be happening. Different types of movement. Detect.

Oops, I lost my mouse. Different types of movement. Deflect. Different types of hair cells. Okay, so I think I kind of went through all this.

The cilia, the hair cells are embedded in the membrane. Each hair cell has this otoconia on it. And then with no head movement, you get you the blah. Sorry. The macula only responds to movement of gravity.

So these otoconia, for those of you who have run across or have treated bppv, benign positional vertigo. We have pretty decent information to support that these otoconia break off and end up most often in the posterior semicircular canal. And that's what causes bppv. So these guys are supposed to stay, you know, hanging out on the otolithic membrane. Sometimes they can break off, and we really don't know why.

It could be from a blow to a head or a fall, but it could just be. It breaks off and it's floating around in one of the semicircular canals and it causes bppv, which is a whole other talk that I did on pt.com and I'll do it for you guys if you like. But just so you have a sense of, you know, now you understand all this anatomy, you know, what is bppv? It's. It's free floating oticonia, which is not cool.

We don't want those floating around anywhere.

All right. Oh, sorry. So, any. I don't have a slide here for questions, but I'll stop for a second. Any questions about the.

You have the three semicircular canals, ampulla on each end, cupula inside the ampulla. Move the head, move the cupula, detect movement. And you have two otoliths on each side. You have a macula inside each otolith. You have gravity that can pull on the macula.

Or you have linear acceleration and deceleration. Right? Not just linear movement. So if you're walking at a steady speed, going for a stroll with your friends, or doing your power walk, it's not your otoliths that are talking to you, it's your semicircular canals. If you accelerate all of a sudden or decelerate, then your otoliths come into play.

So any questions on that piece? That's really the peripheral structures. Let's see. See, what do we know about genetic susceptibility to hair cell damage in the vestibular system? I don't know what we know.

I know nothing. Sorry. I don't know anything about the genetics of it. You know? Is it hereditary?

I couldn't tell you. I hope not, because my dad had it and it was annoying. I know that it's a normal part of aging to lose the hair cells in all three of the structures. The canals, the otoliths, and the cochlea. It's a normal part of aging.

Why? Some people have it worse than others. I don't know if you have happen to have a patient who did not get a vaccine for measles or rubella. Those two diseases can damage. And rubella can actually just damage, destroy all the hair cells.

So if you have someone from a foreign country who didn't get vaccinated when they were young. That's one reason that they might have more loss when they're older, because they started with less. Other than that. I'm sorry, I can't help you with that. If you find the answer to that question, Sophia, shoot me an email.

That's very interesting. All right, so we talked about the peripheral structures. Now we need to understand, how does this data ascend? How do we use the data? Right.

What good is a receptor if it's not connected to the hole?

So how the data is transmitted is on the eighth cranial nerve. And at this point, most resources that I use call it the vestibulocochlear nerve. I was reading one old article the other day, and it was calling it the auditory nerve. And I'm looking, I'm looking, I'm like, oh, my gosh, they're going to ask me, what's the auditory nerve? And I don't know what it is.

They were just misusing that word. It's the vestibular cochlear nerve. It carries the sensory data from both the vestibular system. So semicircular canals and otoliths are considered vestibular system. The cochlea, it's going to travel on the internal auditory canal along with the facial nerve and the labyrinthine artery.

So this is significant if you deal with people who have head injury. Right. A blow to the head, to the side of the head, can fracture the temporal bone and cause damage to eighth cranial nerve and seventh cranial nerve, which is the facial nerve. It's going to enter the brain stem at the pontomedullary junction. And the vestibular nerve.

Well, vestibular system is one of my favorite things to talk about. So, of course, vestibular nerve is my favorite peripheral nerve, my favorite cranial nerve. Yes, I have a favorite cranial nerve. It's the eighth one because it's really cool. It's actually two nerves in one.

It's the vestibular nerve and it's the cochlear nerve. And what they share is an epineurium, but they're two separate nerves. So the vestibular portion has two divisions, has a superior and inferior. The superior vestibular nerve carries data from the utricle, from the horizontal canal and the anterior semicircular canal. Oh, sorry about the typo.

I thought I caught all of them. Carolyn. I didn't. The inferior vestibular nerve contains data from the saccule. Sorry.

And the posterior semicircular canal and the branches. So all those little hair cells I was pointing to, and then they terminate in a branch. The individual branches are going to enter what's called Scarpa's ganglion, and then they emerge to form the eighth cranial nerve. So that's not my picture yet. The primary afferents reside in Scarpa's ganglion.

And these are bipolar ganglion cells, which means they can fire either as an excitatory or an inhibitory. They're pretty advanced systems, right? Reptiles do not have vestibular systems. See, you needed to know that, right? If you have a pet frog, he doesn't have a semicircular canal.

Scarpa's ganglion is in the internal auditory canal. So this here's my picture. So this is my favorite picture of the nerve. It's not my favorite picture of the other structures, but it's my favorite picture of the nerve because you can really see. See the anatomy.

So here are the canals, right? Three canals. And you see, the artist has really excised away all the bone. So the vestibule is just, like, gone. All the perilymph is gone.

They took it out. So you can see the utricle and you can see the saccule. And here, what you see is Scarpa's ganglion. You have superior and you have inferior. So you see the primary afferents coming from the structures into the superior ganglion and the inferior ganglion.

And then you can also see here is. It's kind of tucked away under the facial nerve, the cochlear nerve. So these. All these afferents right here are leaving the cochlea and coming into the cochlear nerve. And then if we follow this down, right down like this, the vestibular nerve and the cochlear nerve are eventually going to come together, and they form like a rope.

Right, let's get in the camera. So it's gonna be like an X like that. And then the epineurium is gonna surround them, and the facial nerve will be next to it. Here we go. It'll be next to it, Right?

So the facial nerve is already formed. It's doing its own thing. But the vestibular nerve and the cochlear nerve are gonna come together in like, a rope and be surrounded by epineurium. So they're gonna share anatomy, right? It's all gonna move through the internal auditory canal.

They're going to share an epineurium, but they're really two separate nerves. And what's pretty cool now is when you have someone with an acoustic neuroma. So a neuroma on the cochlear portion. The surgery nowadays is they can just get it back in the days where the dinosaurs roamed. When I was in the clinic full time, when you had someone with an acoustic neuroma, they would not go in there with a laser, they would go in there with a knife and the poor guy would have a loss of hearing because they cut the nerve, have a facial droop because they nick the facial nerve and be dizzy because they nick the vestibular nerve.

So it was a pretty complicated rehab. And this one particular gentleman I'm thinking of, I said, well, at least the ringing in your ear is gone now. Oh no, the ringing is still there. And he was off balance and he had just a little tiny sort of annoying droop in his face. So that doesn't happen as much anymore because they can go right in and get the neuroma.

So it's great I think, being in this country because the medicine is so advanced. So this is a great picture if you're trying to visualize the nerve. And let me just go back. Right, so the primary afferents reside in Scarpa's ganglion and there's bipolar ganglions in there. So this is Scarpa's ganglion.

You see, there's a superior and an inferior. So every hair cell sends a fiber into the ganglion, which means when you lose hair cells, right, you lose input. You lose input because there's less data going into Scarpa's ganglion. And then eventually it's going to become the eighth ganglion, cranial nerve.

Alright, here's a slightly different picture. I personally don't like this picture as well, but I like to offer several because I know everyone has a different kind of learning style. So here you see Scarpa's ganglion right here and the facial nerve. And you see they're trying to show you how everything is going into the internal auditory canal. So here's the edge.

See if I can get the pointer. Yeah, there's the edge of the internal auditory canal. So you see how the cochlear version is going to meet up with the vestibular portion inside the internal auditory canal. Right? They're going to meet up, so they're very separate until they actually exit through this canal.

I'm just going to move that.

So each hair cell sends an individual afferent and they can either use Spartamate or glutamate, which is excitatory, and then the central processes from both ganglion unite to form the eighth cranial nerve. And vestibular afferents, they do not cross the midline. So the right side, you know, goes to the right side, the left side goes to the left side. And if you remember from your neuroanatomy class, way back whenever that was, it's called an ssa. It's a special somatic afferent.

So it takes afferent data from two of the special senses, vestibular and hearing, and it brings it to first the brainstem. I'm not going to talk about the hearing data. Where it goes, I don't really know that much about it. I'm just going to talk about the vestibular data. And most of the vestibular data does not ascend all the way to the cortex, right?

Most of it gets processed at a lower level than that. But that's the function of an ssa, a special somatic afferent. It's to bring information from the special senses into the central system.

So what are the main targets? If it's not going centrally, you have the vestibular nuclear complex and the cerebellum. These are the main targets. Other targets are these cell groups. These are minor vestibular nuclei.

You don't see them mentioned in very many references. So we don't know that much about them. It's very hard to study vestibular system, right? You have to use higher, you know, higher level animals, which is not done that much anymore in this country. So we don't know as much about it.

And then the other important target of vestibular data are the motor nuclei of the extraocular muscles, right? So cranial nerves 3, 4 and 6.

So here's how it goes, right? It goes from Scarpa's ganglia, which I just showed you, along the eighth cranial nerve, which is in the internal auditory canal, to the four vestibular nuclei, superior, medial, lateral, and then the inferior vestibular nuclei is sometimes also called Diter's nuclei. I'm really only going to talk about these four. I'm not going to talk about these minor nuclei. These nuclei are located in the rostral medulla and the caudal pons, right?

So in the brain stem. So here's my picture. And you see that the artist has excised the cerebellum, right? So here's the cerebellar peduncles. He's got them, all three of them together.

But the cerebellum should be, you know, hanging off the back here. But it's Not. He took them off so that we could see. Here's the superior vestibular nuclei. Here's the lateral vestibular nuclei.

Here's Diter's nuclei, which is also called the inferior. And then the medial vestibular nuclei is right there, that big one in the center. And here you see the motor nuclei of cranial nerve 6 is more inferior, and then III and IV are more superior. Right. So if we go back, right, we have.

We have movement of fluid, deflects the cupula, deflects the macula. You get depolarization of the primary afferents that connect to the hair cells. It goes to Scarpa's ganglion, eighth cranial nerve, and then it's going to synapse either in one of the vestibular nuclei or one or more of the motor nuclei of the oculomotor muscles. Right. So here's all four vestibular nuclei.

And then the oculomotor nuclei that control eye movement are 3, 4, and 6. Right cranial nerve 3, 4, and 6. So 6 is more inferior, 3 and 4 are more superior. You with me out there?

I got 35 people logged in. Is anyone there? So weird doing this.

Okay, so this slide is not on the quiz or the test. It's what I call my. What I tell my students. Nice to know, because it gets a little complicated after a while. The superior and the medial vestibular nuclei are relays for the vor.

So we're going to talk about the VOR in a second. The medial vestibular nuclei also contributes to the vestibulospinal reflexes. So that's going to help us coordinate eye and head movement. And the more I study posture, the more I study balance, the more I study, you know, upright control, the more convinced I am that the end game, the goal is to keep the eyes steady over the trunk. It's not so much the head and the neck, but it's the eyes.

Right, Because I want my visual data to come in clearly. So that's just an opinion I have based on reading a lot of stuff. So the medial vestibular nuclei helps do that. The lateral vestibular nuclei is the principal nucleus for the vestibulospinal reflex, which is very important in keeping us upright. And then the inferior vestibular nuclei does not have any output of its own.

It's going to go. It's going to connect all the other three. And then, of course, all of this data is going to cerebellum. Right. Everything has to end up in Cerebellum.

So cerebellum can do its job of coordination and postural control.

So this is just where the input is coming from. Again, nice to know. Not on the quiz. Superior gets input from the semicircular. Medial gets input from the semicircular.

Lateral gets input from other nuclei, utricle and the saccule. Inferior gets input from the saccule. So it's all very interconnected, Right? Intertwined.

So how do we use this data? Right. What do we do with vestibular data? So I know about velocity, angular velocity, linear acceleration, and gravity. Well, do I do anything with it for motor control?

Of course I do. Right. So I get this. I get output from Scarpa's ganglia along eighth cranial nerve to the superior vestibular nucleus to the medial longitudinal fasciculus to cranial nerves 3, 4, and 6. So I'm going to control eye movement and not the voluntary eye movement.

Like when I say to you, oh, look over here, and you move your eyes, it's involuntary movement that keeps the eyes steady while the head is moving. Right. That's the vor. Keep the eyes steady while the head is moving. How do I do that?

Well, I have to have output from vestibular, which detects head movement, onto ocular motor, which controls eye movement. Well, here it is. Superior vestibular nuclei to the medial lateral fasciculus to the three cranial nerve nuclei that control eye movement. You also have from the medial vestibular nuclei. Same thing.

Medial longitudinal fasciculus to cranial nerves 3, 4, and 6. But then it's also going to ascend to what's the interstitial nucleus of Cajal? If you've never heard of that, don't worry about it. I didn't either until I started doing this. It's not even on this picture.

But it's up here. It would be like up here somewhere. It's a relay station.

All right. And then inferior to the medial lateral to, again, the trochlear and the oculomotor nuclei. So you have a lot of output from the vestibular nuclei onto the oculomotor nuclei. Right. These nuclei, the extraocular nuclei that control eye movement 3, 4, and 6.

So, you know, you can infer that from the anatomy because the structure is right behind the iris. But now you can also look at the neurology of it. Now, it doesn't really happen. It does, because the vestibular nuclei are connected to these extraocular nuclei that are eventually going to control eye Movement, the efferent output is also going to descend. Right.

So we have vestibular nuclei and ascending data, which is mostly going to cranial nerve iii, IV and vi and to the cerebellum, not so much to the cortex. There's a little bit that goes to, of course, the thalamus, because thalamus is like, cheers. Everybody goes there. Right. But there's not a lot of vestibular data going to, you know, cortex, where you're really just perceiving it.

You know, it's there, it's mostly in the background. When the efferent data descends, it helps us control posture. Right. It descends to the alpha motor neuron, LAMINA7, N8, and then to the C spine segments. So what does that mean?

It means it helps activate extensors in the neck and the upper trunk. Mostly the upper trunk. You see the C spine. C spine segments right here. Right.

So you have lateral vestibular nuclei. Here's the lateral vestibulospinal tract right here, which goes directly to alpha motor neuron. If I push you and your head accelerates quickly toward the ground, what's going to happen? Protective extension in your arms and extension of the head and neck to keep you back. That comes from the lateral vestibulospinal tract.

Here's the medial lateral fasciculus. It's fed by the medial vestibular nuclei and then the inferior olivary nucleus. We don't know as much about it in humans as we do in cats. And this pathway runs down all the segments to all four extremities in cats. So it goes down the whole spinal cord.

It does not do that in humans. This inferior olivary nucleus to the medial reticular formation creates a track that pretty much stops, we think, in the. In the C spine. But you see this axillary off to the cerebellum, Right. Going to the cerebellum.

So helping us control posture. So you have vestibular data that's going to ascend and help us control movement of the eyes. And you have vestibular data that's going to descend. That helps us control posture and upright. Especially in response to sudden movement.

Right. Especially of the head. A sudden movement of the head.

So here's my fancy slide on pathways. If you have bad memories of pathways. I have bad memories of physics. The pathways don't really bother me. Physics.

You can sort of, you know, take a. Take a break right now and ignore me. But I'm just going to show you. Here's the vestibulospinal pathway. That's the biggest one.

It's the most highly myelinated one, which means it's the fastest one. Here's the ascending pathways. And here, this picture is the interstitial nucleus of Cajal. Let's see, I thought efferent descends and afferent ascends. Well, it's.

It's afferent is data that comes from. From the periphery into the central system. Efferent is what comes from the. From the central system out to control movement. So.

So even though this is anatomically the pathway is ascending, it's really an efferent pathway because it's going to control movement, it's going to control eye movement. So efferent pathways effect. They create movement. So it's kind of, I don't know, anatomical dilemma, because technically it's ascending, but it's an efferent pathway. So in general, you're right, Vicki, but it just has to do with what this pathway does, which is control movement, controls movement of the eye.

That's really the true definition of an efferent pathway. It controls movement. And I've looked for a picture for years with the descending pathways on one and the ascending pathways on the other, because I find this picture a little overwhelming myself, and I haven't had good luck.

So the vestibular nuclei are primarily motor reflex connections. They're going to innervate the extraocular muscles, part of the reticular formation, and especially the cerebellum. There's just modest projections to the cortex, and even that is going through the thalamus. So there's no direct connection from vestibular nuclei to the cortex. It's going.

It's kind of getting relayed through the thalamus.

All right, so any questions on pathways or ascending and descending data? How the vestibular system sort of exerts control over the motor system?

All right, so we will keep going. And I think, you know, to kind of finish up, it's important to think about the importance of the data. You know, why did this system develop in humans? Why is it so highly developed in humans? Why do we need it?

It's because the postural demands of being upright on two legs are so much higher than the postural demands of a quadruped. And even, you know, a lot of the primates will keep a hand down. So, you know, it's the two legs and maybe one hand down, you know, so it's not true. Quadruped, but they still are not upright in the way that we are with the center of Gravity really ahead of the body all the time. So when you take the center of gravity and put it in front of the structure, you automatically create instability.

So we developed this system to detect movement and gravity so we could stay upright. It's why reptiles don't have it. They don't, they don't need it. So it's the cerebellum that's the major recipient of outflow from the vestibular nuclear complex. So in addition to sending data to the extraocular motor nuclei and data descending to the medial lateral to create the medial and lateral vestibulospinal tracts, we're sending a ton of vestibular data to the cerebellum.

And you have direct projections from the cerebellum to the vestibular nuclei. So it's a two way street. Right. And the cerebellar nuclei sit in the brain stem right next to the vestibular nuclei. So there's all these interconnections between the cerebellar nuclei and the vestibular nuclei.

Parts of the cerebellum adjust what's known as the gain of the vor. Right. So how fast does the response happen? And it's why your patients with cerebellar damage have nystagmus and difficulty with eye movement, because they lose this ability to adjust the gain of the vor. And the vestibular labyrinth is the only sensory organ that sends a primary afferent directly to the cerebellum.

So cerebellum gets ascending data from, you know, light, touch and pressure and all that. It's usually a two synapse pathway, right? Usually takes two from vestibular. It's a primary afferent right into cerebellum.

We kind of already went over this part. Right.

So most of the portions of the vermis, which is the midline, respond to vestibular. And sometimes the flocculus, the nodulus, the uvula, and the vestigial nucleus are called the vestibular cerebellum. So these are actually the newest parts of the cerebellum, the youngest parts of this overall structure. And they're sometimes grouped together as the vestibular cerebellum. It's hard, it's been hard for me to find a decent picture of all the structures together because of the way they're organized.

So you can see this is actually like a posterior view of the cerebellum. You see the vermis here and then the flocculus and the nodulus. Really, this is an artist's rendition, really. These structures are more anterior than this kind of curving under. But this artist was nice and put it inferior so that we could.

We could see it. And then here's another where they call the whole piece the vestibulocerebellum. Don't see that a lot. And then here's. I think here's the best one.

So this is the anterior surface of the cerebellum. If you look here, this would. This. This is where the peduncles were. So this is where the cerebellum was attached to the back of the cortex.

So this would be, you know, if we were doing a dissection project, you dissected the cerebellum off the cortex so you could look at the cerebellum on its own. So that's what you're looking at. And then you can see the superior vermis here on this inferior anterior surface. And here's the flocculus right here in blue. That was nice of the artist to make it blue for us.

And then you know that the floor of the cerebellum makes up the roof of the fourth ventricle. Right. So the artist is telling you, here's where the ventricle was. So I think this is kind of the best picture, although it's a little busy with the words to see, you know, where's the data going? It's going to the midline of the cerebellum and the anterior inferior part of the cerebellum, which is really the newest part of this structure.

All right, so let's talk about the reflexes, because this is how we can assess or talk to the vestibular system and find out, you know, how's it doing, how's it working? And the one we know the most about is the VOR vestibular ocular reflex. The vestibular spinal reflex is a little harder to study and to. We don't usually evaluate it in the clinic, but I just felt to be complete. Right.

Since we're going to spend two hours, that I wanted to cover it. But just know that if it seems a little vague, it's because we don't know that much about it. So the function of the VOR is to keep the eyes steady while the head is moving. Right. So if I look into the camera, take my glasses off, and I look straight in and I move my head, my eyes are staying steady.

What if I do. Is that better if I do it like that? Oh, yeah. All right, so I'm going to look at the camera, not at the picture. And move my head.

And you should be seeing that my eyes are staying very steady. You could try it right now if you want. You would hold the tip of a pencil and stare at that and move your head back and forth. So that's the horizontal VOR and that's the vertical vor. It keeps the eye steady while the head is moving.

And if I want, I can suppress that, right? If I call your name, Sophia, if I call you, you're going to turn your head and your eyes and look at me. You suppressed your vor, so the VOR has to be intact. You have to be able to keep your eyes steady while your head is moving, and you also have to be able to suppress it if you need to. And that tells me it's in full function.

Everything's good. And I have some extra information here. Angular VOR mediated by the semicircular canals, linear mediated by the otolith. Don't worry so much about linear. What we evaluate in the clinic as pts, and those of you audiologists who work in that area, we tend to evaluate only the angular vor.

All right, so keep the eyes steady while the head is moving. And here's how it works. Here's my friend. Unfortunately, he had the top of his cranium excised. He's still kind of happy, though.

Well, yeah, you could say this is a smiley face. He's turning his head to the left, right? Turn my head to the left. And I've given him the instruction, keep your eyes still while you move your head. I gave him that instruction.

So he turned his head to his left. What I need is equal and opposite movement of the eyes, right? I turn my head to the left, my eyes have to move to the right. So I have activation of medial rectus on the left eye, lateral rectus on the right eye. How did that happen?

Because I stimulated the left semicircular canal. The input went through Scarpa's ganglion, which would be over here, somewhere over there, into the vestibular nuclei, into the extraocular motor nuclei of cranial nerve cell 6 and 3, 3 to medial, 6 to lateral. So I turn my head to the left, I need equal and opposite movement to the right. So I get medial and lateral rectus. The gain of the VOR is the degree of the eye movement.

So for every one degree of head movement, I need one degree of eye movement. And I said earlier, it's probably the cerebellum that controls the gain, right? So this input from this canal that went to vestibular Nuclei also went to the cerebellum at the same time so that the cerebellum can adjust the gain. Right. And I can move my head up to 220Hz per second and still keep my eyes steady.

That's really fast, right? Because my cerebellum works that fast. This next one is a little more complicated because, of course, I'm not only stimulating one, I'm usually stimulating two. And I'm not only stimulating the left side, I'm also stimulating the right side. So this is here just to give you a headache, really.

I never try and explain the left side and the right side. So because you see the left side as the left side is being inhibited, it's blue, the right side is being facilitated, it's red. And after a while, you give yourself a migraine and you can call it a vestibular migraine if you like. So I like this picture the best. It gives me a sense of what's happening without giving me a headache.

And this is another even more complicated picture that's going to show you directly which nuclei and which muscles here. Right. So I like to give you a variety. So when you go back to review, you can look at it. But I'm not really going to go over this particular one so much because I find it confusing.

All right. So VOR keeps the eyes steady while the head is moving. And we have a multitude of ways we can assess the VOR so we can establish the integrity of the VOR and start to think about is the vestibular system intact and working or not? So my patient is dizzy. I take a good history.

They don't have bppv. The first thing I do is I assess eye movement first, then I assess the vor. The vestibulospinal reflex. It's a little harder to talk about. Right.

It senses head movement in the head relative to gravity. So you know that the otoliths are part of that because there are gravity sensors. It has output to the anterior horn cells that innervate the extensors of the neck, the trunk and the extremities. And as you move distally, neck, trunk extremities, you get less and less innervation. Right.

The innervation starts to. To sort of thin out. It's most in the neck, then the trunk, least in the extremities. It projects to the anti gravity muscles through mostly the vestibulospinal tracts, especially the lateral. If you remember from the picture back a few slides, it's the biggest.

It's the most highly myelinated which makes it the fastest. So especially the lateral vestibulospinal tract, it's also going to go to medial and then reticulo spinal tract.

So it helps us maintain upright and reference to gravity. So we know that the otoliths are always firing, right? They're always telling us where gravity is. So I use the vestibular spinal reflex to keep me oriented to gravity. And I said to you earlier, it's my personal opinion that one of the main end games of our postural control system is to keep the eyes level with the trunk, right?

So basically keeping the eyes perpendicular to gravity. And I really believe this is one of the main. You know, that's one of the main things the system is always trying to achieve. So one way to achieve that is to keep the neck muscles attuned. So my head stays vertical, stays parallel to gravity, right?

So the vestibulospinal reflex is one way we do that. It keeps the background muscle tone in our postural muscles. So extensors of the neck and the trunk. And there's a much more complex pattern of activation. What most people think it's a.

Is it blah. Sorry, is that it's a compilation of several reflex. So it's not just one reflex. And there's, you know, many, many less studies. Most of the studies are on cats, right?

Most of the studies are on cats. And, you know, they don't have a need for postural control of upright. They're quadrupeds. The need they have for trunk control is completely different than the need we have. So even if we study it, I don't think we get a sense of what it does in humans when we look at a cat.

No, this is the same picture I showed you before, which is probably some part of the vestibulospinal reflex. Here we go. So you see going from the semicircular canal, but also the otolith, which is probably more important to the lateral vestibular nucleus. And it's not identifying this pathway, but it's going through also the medial vestibular nucleus. So it's probably the medial vestibular spinal pathway.

And then you also see from the medial nucleus to the medial longitudinal fasciculus to. This would be an extensor muscle here, right? That would be an extensor muscle. And there's probably more involved in it, right? Because we need this pathway to run the whole.

All the segments of the cervical spine and the upper thoracic to stay upright. So there's probably more to it than what you're seeing right there.

All right, I think I'm done.

Oh, yeah. Let me just point these out and then I'll take questions. The physical therapy. American Physical Therapy association has sections, right? So neurosection, and part of Neurosection is the Vestibular Special Interest Group sig.

You can access the Neurosection website for free, and you can access all the vestibular data in the Vestibular SIG for free. You don't have to be an APTA member at all. There used to be a lot more videos on there. They took some of the videos down, but there's a lot of information. YouTube has a lot of videos.

You have to be careful, right? It's not always correct, but there's some good stuff. And there's some people who actually publish on YouTube Eye movement videos that they've taken with frenzel glasses. So if, you know, you know, frenzel glasses are the biggest glasses that you put on someone when you're assessing their eye movement. And the really expensive glasses videotape the eye movements.

So you can find on YouTube Eye movement videos that were taken by professionals, and they kindly put them up there for people like me who don't have any fancy glasses. So those are great. The Geriatric Examination toolkit is wonderful. If you Google that, they have tons of tests and measures, all kinds of things. Not as far as I know, related so much to audiology, more related to OT and pt.

And then there's also vita. And then something that's not on this slide is called rehabmeasures.org so it's rehab r ehab measures. And then you can put in, you know, you can search a test, so search the VOR and it'll pull up articles, it'll pull up how to do the test, it'll pull up links. It's a free resource and it's fantastic. If you've never gone on there, go poke around in there for 10 minutes and you'll be.

You'll have everything you need. All right. And then I just want to point out my favorite book for this. These resources is out of print, so if you can ever get it on ebay or something, I highly recommend it. It's some of the most clear explanations of vestibular.

And then I read the other day the piece about the cochlea and all those connections, and I understood it on the first try. So it's really clear and it's at a nice level. It's sort of at a graduate ish level. So it's not too basic. If you're into vestibular rehab.

If you work for an ENT and you're doing rehab, you have to have the Herdman book this. I think there's a newer version now. I don't like how it's organized. I'll just say that out loud. But it has a ton of information in it.

All right, so now I'm done.

You're welcome, Vicki. And are there any questions? Can I answer? We got about 10 minutes. Can I answer questions?

My dog got kind of bored with the trash, he says. Second, Dr. Kelly, sorry, just wanted to thank you on behalf of the audiologist. I think it is great to hear from our colleagues in other professions. And this was really an outstanding webinar. And it was great that you took questions throughout because I think it helped.

I loved Vicki's question as well about the afferent and the efferent, ascending and descending. So some good stuff came out in the middle as well. I just want to remind everyone that the CEU test for this course does expire within a week. So if you're earning CEUs today, please make sure that you log into your account within a week and take the test. If you try to take it after a week, it will no longer be available and you won't be able to earn the CEUs.

Also, I just wanted to point out that we have an international audience today. I see we have some of our colleagues from the Middle east logged in. I don't even know what time it is out there, but thank you. And I don't see any other questions coming in the Q and A box. Sometimes we get questions afterward from folks.

So, Dr. Kelly, if it's okay with you, I'll send those along to you if we get any that come in. Oh, yes, definitely send those in. I'll answer them if I can. It's a complicated area, and there's a lot of information about it out there. And the web stuff that I've given you is, for the most part, all free, so easily accessible for you.

So thank you. And Sally just typed in as well. Great presentation and thank you. Thanks to everybody who attended today. We wish you a great afternoon and Dr. Kelly, Hope we get to work.