Welcome to the Huberman Lab podcast where we discuss science and science-based tools for everyday life. I'm Andrew Huberman and I'm a professor of neurobiology and ophthalmology at Stanford School of Medicine. Today my guest is Dr. David Berson, professor of medical science, neurobiology and ophthalmology at Brown University. Dr. Berson's laboratory is credited with discovering the cells in the eye that set your circadian rhythms. These are the so-called intrinsically photosensitive melanopsin cells and while that's a mouthful, all you need to know for a sake of this introduction is that those are the cells that inform your brain embody about the time of day. Dr. Berson's laboratory has also made a number of other important discoveries about how we convert our perceptions of the outside world into motor action. More personally, Dr. Berson has been my go-to resource for all things neuroscience for nearly two decades. I knew of his reputation as a spectacular researcher for a long period of time and then many years ago I cold-called him out of the blue. I basically corralled him into a long conversation over the phone after which he invited me out to Brown and we've been discussing neuroscience and how the brain works and the emerging new technologies and the emerging new concepts in neuroscience for a very long time now. You're going to realize today why Dr. Berson is my go-to source. He has an exceptionally clear and organized view of how the nervous system works. There are many, many parts of the nervous system, different nuclei and connections and circuits and chemicals and so forth, but it takes a special kind of person to be able to organize that information into a structured and logical framework that can allow us to make sense of how we function in terms of what we feel, what we experience, how we move through the world. Dr. Berson is truly one of a kind and his ability to synthesize and organize and communicate that information and I give him credit as one of my mentors and one of the people that I respect most in the field of science and medical science generally. Today Dr. Berson takes us on a journey from the periphery of the nervous system, meaning from the outside, deep into the nervous system, layer by layer, structure by structure, circuit by circuit, making clear to us how each of these individual circuits work and how they work together as a whole. It's a really magnificent description that you simply cannot get from any textbook, from any popular book and frankly, as far as I know, from any podcast that currently exists out there. It's a real gift to have this opportunity to learn from Dr. Berson. Again, I consider him my mentor in the field of learning and teaching neuroscience and I'm excited for you to learn from him. One thing is for certain, by the end of this podcast, you will know far more about how your nervous system works than the vast majority of people out there, including many expert biologists and neuroscientists. Before we begin, I'd like to emphasize that this podcast is separate from my teaching and research roles at Stanford. It is however part of my desire and effort to bring zero cost to consumer information about science and science-related tools to the general public. The overview I did with longevity research doctor and Inside Tracker's founder, Dr. Gil Blander, is out now on their podcast, the longevity by design podcast. And a link to that interview can be found in today's show notes. And now for my discussion with Dr. David Berson. Welcome. Thank you. So nice to be here. Great to have you. For more than 20 years, you've been my go-to source for all things, nervous system, how it works, how it's structured. So today I want to ask you some questions about that. I think people would gain a lot of insight into this machine that makes them think and feel and see et cetera. If you would, could you tell us how we see, you know, a photon of light enters the eye. What happens? Right. I mean, how is it that I look outside, I see a truck drive by or I look on the wall, I see a photo of my dog. How does that work? Right. So this is an old question, obviously. And clearly in the end, the reason you have a visual experience is that your brain is some pattern of activity that associates with the input from the periphery. But you can have a visual experience with no input from the periphery as well. When you're dreaming, you're seeing things that aren't coming through your eyes. Are those memories? I would say in a sense they may reflect your visual experience. They're not necessarily specific visual memories, but of course they can be. But the point is that the experience of seeing is actually a brain phenomenon. But of course, under normal circumstances, we see the world because we're looking at it and we're using our eyes to look at it. And fundamentally, when we're looking at the exterior world, it's what the retina is telling the brain that matters. So there are cells called ganglion cells. These are neurons that are the key cells for communicating between eye and brain. The eye is like the camera. It's detecting the initial image, doing some initial processing. And then that signal gets sent back to the brain proper. And of course, it's there at the level of the cortex that we have this conscious visual experience. There are many other places in the brain that get visual input as well doing other things with that kind of information. So I get a lot of questions about color vision. If you would, could you explain how is it that we can perceive reds and greens and blues and things in that sort? Right. So the first thing to understand about light is that it's just a form of electromagnetic radiation. It's vibrating. It's oscillating. But light if say it's vibrating, it's oscillating. You mean that photons are actually moving? Well, in a sense, photons are, they're certainly moving through space. We think about photons as particles. And that's one way of thinking about light. But we can also think of it as a wave, like a radio wave. Either way is acceptable. And the radio waves have frequencies like the frequencies on the radio dial. And certain frequencies in the electromagnetic spectrum can be detected by neurons in the retina. Those are the things we see. But there's still different wavelengths within the light that can be seen by the eye. And those different wavelengths are unpacked in a sense or decoded by the nervous system to lead to our experience of color. Essentially different wavelengths give us the sensation of different colors through the osfaces of different neurons that are tuned to different wavelengths of light. When a photon, so when a little bit of light hits my eye, goes in, the photoreceptors convert that into electrical signal. How is it that a given photon of light gives me the perception, eventually leads the perception of red versus green versus blue? So if you imagine that in the first layer of the retina where this transformation occurs from electromagnetic radiation into neural signals, that you have different kinds of sensitive cells that are expressing their making different molecules within themselves, that's the purpose of absorbing photons, which is the first step in the process of seeing. Now it turns out that altogether there are about five proteins like this that we need to think about in the typical retina. But for seeing color, really it's three of them. So there are three different proteins. Each absorbs light with a different preferred frequency. The nervous system keeps track of those signals, compares and contrast them to extract some understanding of the wavelength composition of light. So you can see just by looking at a landscape, or it must be late in the day because things are looking golden. That's all a function of our absorbing the light that's coming from the world and interpreting that with our brain because of the different composition of the light that's reaching our eyes. Is it fair to assume that my perception of red is the same as your perception of red? Well, that's a great question. And that mine is better. I'm just kidding. It's a great question. It's a deep philosophical question. It's a question that really probably can't even ultimately be answered by the usual empirical scientific processes because it's really about an individual's experience. What we can say is that the biological mechanisms that we think are important for seeing color, for example, seem to be very highly similar from one individual to the next whether it be human beings or other animals. And so we think that the physiological process looks very similar on the front end. But once you're at the level of perception or understanding or experience, that's something that's a little bit tougher to nail down with the sort of scientific approaches that we approach biological vision, let's say. You mentioned that there are five different cone types, essentially, the cones being the cells that absorb light of different wavelengths. I often wondered when I had my dog what he saw and how his vision differs from our vision. And certainly there are animals that can see things that we can't see. What are some of the more outrageous examples of that? I've seen things in the extreme. Dogs, I'm guessing C. Reds more as oranges, is that right? Because they don't have these the same array of neurons that we have for seeing color. Right. So the first thing is it's not really five types of cones. There are really three types of cones. And if you look at the way that color vision is thought to work, you can sort of see that it has to be three different signals. There are a couple of other types of pigments. One is really mostly for dim light vision when you're walking around in a moonless night and you're seeing things with very low light. That's the rod cell that uses a zone pigment. And then there's another class of pigments will probably talk about a little bit later, the smell and opsin pigment. I thought you were referring to like ultraviolet and infrared and that sort of. Right. So in the case of a typical, well, let's put it this way in human beings. Most of us have three corn types and we can see colors that stem from that in most mammals, including your dog or your cat. There really are only two corn types and that limits the kind of vision that they can have in the domain of wavelength or color as we'd say. So really a dog sees the world kind of like a particular kind of color blind human might see the world. Because instead of having three channels to compare and contrast, they only have two channels. And that makes it much more difficult to figure out exactly which wavelength you're looking at. Do color blind people suffer much as a consequence of being color blind? Well, you know, it's like so many other disabilities. We are, you know, the world is built for people of the most common type. So in some cases, the expectation can be there that somebody can see something that they won't be able to if they're missing one of their corn types, let's say. In those moments, that can be a real problem. You know, if there's a lack of contrast to their visual system, they will be blind to that in general, it's a fairly modest visual limitation as things go. You know, for example, if not being able to see a chootly can be much more damaging, not being able to read, you know, fine print, for example. I suppose if I had to give up the ability to see certain colors or give up the ability to see clearly, I certainly trade out color for clarity. Of course, colors are very meaningful to us as human beings, you know, so we would hate to give it up. But obviously dogs and cats and all kinds of other mammals do perfectly well in the world. Yeah, because we take care of them. I spent most of my time doing care of that dog. He took care of me too. Let's talk about that odd photopigment. Photo pigment, of course, being the thing that absorbs light of a particular wavelength. And let's talk about these specialized ganglion cells that communicate certain types of information from eye to the brain that are so important for so many things. What I'm referring to here, of course, is your co-discovery of the so-called intrinsically photosensitive cells, the neurons in the eye, that do so many of the things that don't actually have to do with perception, but have to do with important biological functions. What I would love for you to do is explain to me why, once I heard you say, we have a bit of fly eye in an hour eye. And you showed this slide of a giant fly from a horror movie trying to attack this woman. And maybe it was an eye also. So what does it mean that we have a bit of a fly eye in our eye? Yeah, so this is this last pigment is a really peculiar one. When you can think about it as really the initial sensitive element in a system that's designed to tell your brain about how bright things are in your world. And the thing that's really peculiar about this pigment is that it's in the wrong place in a sense. When you think about the structure of the retina, you think about a layer cake, essentially. You've got this thin membrane at the back of your eye, but it's actually a stack of thin layers. And the outermost of those layers is where these photo receptors you were talking about earlier are sitting. That's where the film of your camera is, essentially. That's where the photons do their magic with the photo pigments and turn it into a neural signal. I like that. I've never really thought of the photo receptors as the film of the camera, but that makes sense. Or like a sensitive chip on you know, CCTV chip in your cell phone is the surface on which the light pattern is imaged by the optics of the eye. And now you've got an array of sensors that's capturing that information and creating a bit map, essentially. But now it's in neural signals distributed across the surface of the retina. So all of that was known to be going on 150 years ago. A couple of types of photo receptors, cones and rods. If you look a little bit more closely, three types of cones. That's where the transformation from electromagnetic radiation to neural signals was thought to take place. But it turns out that this last photo pigment is in the other end of the retina, the innermost part of the retina. That's where the so called ganglion cells are. Those are the cells that talk to the brain. The ones that actually can communicate directly. What information comes to them from the photo receptors. And here you've got a case where actually some of the output neurons that we didn't think had any business being directly sensitive to light. We're actually making this photo pigment absorbing light and converting that to neural signals and sending to the brain. So that made it pretty such a surprising and unexpected, but there are many surprising things about these cells. So and what is the relationship to the fly eye the right so the link there is that if you ask how the photo pigment. And then the link communicates downstream from the initial absorption event to get to the electrical signal. That's a complex cellular process involves many chemical steps. And if you look at how photo receptors in our eyes work, you can see what that cascade is, how that chain works. In the eyes of flies or other insects or other invertebrates. There's a very similar kind of chain that but the specifics of how the signal gets get from the absorption event by the pigment to the electrical response that the nervous system can understand are characteristically different between fuzzy furry creatures like us. And insects, for example, like the fly, I say so these funny extra voter receptors that are in the wrong layer doing something completely different are actually using a chemical cascade that looks much more like what you would see in a fly voter receptor than what you would see in a human voter receptor, a rod or a cone, for example. And it sounds like it's a very primitive part of primitive aspect of biology that we maintain exactly right. And despite the fact that dogs can't see as many colors as we can and cats can see as many colors as we can we have all this extravagant stuff for seeing color and then you got this other pigment sitting in the wrong not wrong but in a different part of the eye sending processing light very differently. And sending that information into the brain so what do these cells do I mean presumably they're there for a reason there are and the interesting thing is that one cell type. Like this carrying one kind of signal which I would call a brightness signal essentially can do many things in the brain when you say brightness signal you mean that it like right now I have these cells I have these cells I do. I mean I'm joking I hope I have these cells mine and they're paying attention to how bright it is overall but they're not paying attention for instance to the edge of your year or what else is going on in the room right so so it's the difference between knowing what the objects are on the table and knowing whether it's bright enough to be daylight right now. So what why does your nervous system need need to know whether it's daylight right now well one thing that needs to know that is your circadian clock you know if you travel across time zones to Europe now your internal clock thinks it's California time but the rotation of the earth is you know for you know a different part of the planet you're the rising and setting of the sun is not at all what your body is anticipating so you've got an internal representation of the rotation of the earth in your own brain that's your brain. That's your circadian system is keeping time but now you've played a trick on your nervous system you put yourself into different place where the sun is rising at the quote wrong time well that's not good for you right so you got to get back on track one of the things this system does is sends a oh it's daylight now signal to the brain which compares with its internal clock and if that's not right it tweaks the clock gradually until you get over your jet lag and you feel back on track again. So the jet lag case makes a lot of sense to me but presumably these elements didn't evolve for jet lag right so what what are they doing on a day to day basis right well one way to think about this is that the clock that you have in not just your brain in all the cells we were almost all the cells of your body they're all oscillating they're all you know they got little clocks and then they themselves they're all they're all clocks. You know they need to be synchronized appropriately and the whole thing has to be built in biological machinery this is actually a beautiful story about how gene expression can control gene expression and if you set it upright you can set up a little thing that just sort of a long at a particular frequency in our case it's humming along at 24 hours because that's how our Earth rotates and it's all built into our biology so this is great but the reality is that the clock can only be so good I mean we're talking about biology or it's not precision engineering and so it can be a little bit off well also it doesn't it's in our brain so it doesn't have access to any regular unerring signal well if in the absence of the rising and setting of the sun it doesn't if you put someone in a cave they're biological clock will keep time to within a handful of minutes of 24 hours that's no problem for one day but if this went on without any correction eventually you be out of phase and this is actually one of the things that blind patients often complain about they've got retinal blindness is insomnia and or sleep away from the normal night exactly they're not synchronized their clock is there but they're drifting out of phase because their clocks only good to you know 24.2 hours or 23.8 hours though by little they're drifting so you need a synchronization signal so even if you never across time is on it's not of course we didn't back on the Savannah we stayed within walking distance of where we were you still need a synchronizer because otherwise you have nothing to actually confirm when the rising and the setting of the sun is that's what you're trying to synchronize yourself to I'm fascinated by the circadian clock and the fact that all the cells of our body have essentially a 24 hour ish clock in them right we hear a lot about these circadian rhythms and circadian clocks fact that we need light input from these special neurons in order to set the clock but I've never really heard it described how the clock itself works and how the clock signals to all the rest of the body when you know the liver should be doing one thing and the stomach should be doing another I know you've done some work on the clock so if you would just maybe briefly describe where the clock is what it does and some of the you know top contour of how it tells the cells of the body what to do right so the first thing to say is that is you said the clock is all over the place most of the tissues in your body have clocks we probably have what millions of clocks yeah I would say that's that's probably fair you have millions of cell types you might be have millions of clocks that the role of the central pacemaker for the circadian system is to coordinate all of these and this is there's a little nucleus a little collection of nerve cells in your brain this called the superchiasmatic nucleus the SCN and it is sitting in a funny place for the rest of the structures in the nervous system that yet direct retinal input is sitting in the hypothalamus which you can think about as sort of the great coordinator of drives and the source of all our pleasures and all our problems right or most our problems yes it really is but it's sort of you know deep in your brain things that drive you to do things if you freezing cold you put on a coat you you should worry all these things are coordinated by the hypothalamus so this pathway we're talking about from the retina and from these peculiar cells that are encoding light intensity are sending signals directly into a center that's surrounded by all of these centers that control autonomic nervous system and your hormonal systems so this is a part of your your visual system that doesn't really reach the level of consciousness it's not something you think about it's happening under the radar kind of all the time and the signal is working its way into this central clock coordinating center now what happens then is not that well understood but it's clear that this is a neural center that has the same ability to communicate with other parts of your brain is any other neural center and clearly there are circuits that involve connections between neurons that you know are conventional but in addition is quite clear that there are also sort of humoral effects that things are being or oozing out of the cells in the center and maybe into the circulation or or just diffusing through the brain to some extent they can also affect neurons all swear but the hypothalamus uses everything to control the rest of the body and that's true the superchisematic nucleus this circadian center as well it can get its fingers into the autonomic nervous system the humoral system and of course up to the centers of the brain that organized coordinated rational behavior so if I understand correctly we have this group of cells the superchisemite nucleus it's got a 24 hour rhythm it that rhythm is more or less matched to what's going on in our external world by the specialized set of neurons in our eye but then the the master clock itself the sien releases things in the blood humoral signals that go out various places in the body and they said to the autonomic system which is regulating more or less how alert or calm we are as well as the automatic tracking in our cognition so the I'd love to talk to you about the autonomic part presumably that's through melatonin it's through adrenaline what how is it that this clock is impacting how the autonomic system how alert or calm we feel right so there are pathways by which the superchisematic nucleus can access with the parasympathetic and sympathetic nervous system just so people know that sympathetic nervous system is the one that tends to make us more alert and the parasympathetic nervous system is the portion of the autonomic system makes us feel more calm right in in broad to first yeah to first approximation right so this is both of these systems are within the grasp of the circadian system through hypothalamic circuits one of the circuits that will be I think a particular interest to some of your listeners is a pathway that involves this sympathetic branch of the autonomic nervous system the fighter flight system that is actually through a very serious route innovating the pineal gland which is sitting in the middle of your brain the so called third eye right so this is the main source of melatonin in your body so light comes into my eye yes passed off to the superchisematic nucleus essentially not the light itself but the signal representing the light sure then the SCN the superchisematic nucleus can impact the melatonin system via the pineal right the way this is seen is that if you were to measure your melatonin level over the course of the day if you could do this you know power by hour you'd see that it's really low during the day very high at night but if you get up in the middle of the night and go to the bathroom and turn on the bright full or fluorescent light your melatonin level is slammed to the floor light is directly impacting your home and the signals through this mechanism that we just describe so this is one of the routes by which light can act on your hormonal status through pathways that are completely beyond what you normally would think about right you're thinking about the things in the bathroom or there's the toothbrush you know there's the tube of toothpaste but meanwhile this other system is just counting photons and saying oh wow there's a lot of photons and then let's shut down the melatonin release. This is one of the main reasons why I've encouraged people to avoid bright light exposure in the middle of the night not just blue light but bright light of any wavelength because there's this myth out there that blue light because it's the optimal signal for activating this pathway and shutting down melatonin is the only wavelength of light that can shut it down but am I correct in thinking that if a light is bright enough right it doesn't matter if it's blue light green light purple light even red light right you're going to slam melatonin down to the ground which is not a good thing to happen in the middle of the night right right yeah I mean any any light will affect the system to some extent the blue light is somewhat more effective but don't fool yourself into into thinking that if you use red light that means you're you know you're avoiding the effect you certainly still there and certainly that's very bright it'll be more effective in driving the system than dim blue light would be interesting a lot of people wear blue blockers and in a kind of odd twist of misinformation out there a lot of people wear blue blockers during the middle of the day which basically makes no sense because during the middle of the day is when you want to get a lot of bright light and including blue light into your eyes correct absolutely and not just for the reasons we've been talking about in terms of circadian effects there are major effects of light on mood and seasonal effective disorder apparently is essentially a reflection of this same system in reverse if you're living in the northern climbs and you know you're not getting that much light during the middle of the the winter in Stockholm you might be prone to depression and photo therapy might be just the ticket for you and that's because there's a direct effect of light on mood there's an example where if you don't have enough light it's a problem so I think you're exactly right it's not about is like good or bad for you it's about what kind of light and when that makes the difference the general of thumb that I've been living by is to get as much bright light in my eyes ideally from sunlight anytime I want to be alert right and doing exactly the opposite when I want to be a sleep yeah we're getting drowsy and there are there are aspects of this that they spin out way beyond the conversation we're having now to things like this it turns out that the incidents of myopia near-sightedness near-sightedness right is strongly related to the amount of time that kids spend outdoors and what direction of effect the more they spend time outdoors the less near-sightedness they have so this is not because they're viewing things at a distance or because they're getting a lot of blue light this sunlight it's a great question it is not fully resolved what the epidemiological what the basis of that epidemiological finding is one possibility is the amount of light which would make me think about this melanopsin system again but it might very well be a question of accommodation that is the process by which you focus on near or far things if you're never outdoors everything is nearby if your outdoors you're focusing far so this is your on your phone right exactly which there's a tremendous amount of interest these days in you know watches and things that count steps I'm beginning to realize that we should probably have a device that can count photons during the day right and can also count photons at night and tell us hey you're getting too many photons you're going to shut down your melatonin at night or you're not getting enough photons today you didn't get enough bright light whether or not's from artificial light or from sunlight that I guess that where would you put it is you put it on top of your head or so you probably want it someplace outward facing right probably what you need is as many photons over as much of the retinas possible to recruit as much of the system you know as possible and thinking about other effects of this non-image forming pathway that involves these special cells in the eye and the SCN you had a paper a few years ago looking at retinal input to an area of the brain which has a fancy name the Perry Hubbenula but names don't necessarily matter that had some important effects on mood and other aspects of light what maybe you could tell us a little bit about what is the Perry Hubbenula oh wow so I mean that's a fancy term but I think the way to think about this is as a chunk of the brain that is sitting as part of a bigger chunk that's really the linker between peripheral sensory input of all kinds or virtually all kinds of whether it's auditory input or tactile input or visual input to the region of your brain the cortex that allows you to think about these things and make plans around them and to integrate them and that kind of thing so you know we've known about a pathway that gets from the retina through this sort of linker center it's called the thalamus and then on on the train station exactly but you want to arrive at the destination right now you're at grand central and now you can do your thing as you're up at the cortex so this is the standard pattern you have sensory input and you're coming from the periphery you've got these peripheral elements that are doing the initial stages of the skin of your fingertips right you know the taste buds on your tongue they're taking this raw information in and they're doing some pre-processing maybe or you know the early circuits are but eventually most of these signals have to pass through the gateway to the cortex which is the thalamus and you've known for years for decades many decades what the major throughput pathway from the retina to the cortex is and where it ends up it ends up in the visual cortex you know you path the back of your head that's where the receiving the center is for the main pathway from retina to cortex but wait a minute there's more there's this little side pathway it goes through a different part of that linking thalamus center it's like a local train yeah from grand central to it's in a weird part of the neighborhood right it's a completely different it's like a little trunk line that branches off and goes out into the hinterlands and it's going to the part of this linker center that's talking to a completely different part of cortex way up front frontal lobe which is much more involved in things like planning or self image or which literally how one was one self into do you feel good about yourself or you know what's your plan for next Thursday you know it's it's a it's a very high level center in the highest level of your nervous system and this is the region that is getting input from this pathway which is mostly worked out in this function by Sam or hitars love I know you had him on the podcast we didn't talk about this path way at all right so day of Fernandez and and Sam and the folks that work with them were able to show that this pathway doesn't exist and get you to a weird place but if you activate it at kind of the wrong time of day animals can become depressed and if you silence it under the right circumstances then weird lighting cycles that would normally make them act sort of depressed no longer have that effect so it sounds to me like there's this pathway from I to this unusual train route through the structure we call the thalamus then up to the front of the brain that relates to things of self perception kind of higher level functions I find that really interesting because most of what I think about when I think about these fancy well or these primitive rather neurons that don't pay attention to the shapes of things but instead to brightness I think up well it regulates my tone of the brain and I think that it's not going to be a lot of the same way as I think up well it regulates melatonin circadian clock mood hunger the really kind of vegetative stuff if you will right and this is interesting because I think a lot of people experienced depression not just people that live at you know in skin and winter and we are very much divorced from our normal interactions with light it also makes me realize that these intrinsically photosensitive cells that set the clock etc are involved in a lot of things I mean they seem to regulate a dozen or more different basic functions I want to ask you about a different aspect of the visual system now which is the one that relates to our sense of balance so I love boats but I hate being on them love the ocean from shore because I get incredibly seasick just off I think it's sick if I think about it too much and once I went on a boat trip I came back and I actually got I got motion sick or wasn't seasick as I was rafting so there's a system that somehow gets messed up they always tell us if you're feeling sick to look at the horizon etc etc so what is the link between our visual system and our balance system and why does it make it snosh sometimes when the world is moving in a way that we're not accustomed to right I realize this is a big question because it involves i movement etc but let's maybe just walk in at the simplest layers of vision vestibular so called balance system and then maybe we can piece the system together for people so that they can understand and then also we should give them some tools for adjusting their nausea when they're when their vestibular system is out of whack cool so I mean the first thing to think about is that the vestibular system is designed to allow you to see how you're or detect sense how you're moving in the world through the world it's a funny one because it's about your movement in relationship to the world in a sense and yet it's sort of interoceptive in the sense that it is really in the end sensing the movement of your own body okay so interception we should probably delineate for people is when you're focusing on your internal state as if it's something outside you right but is it a it's a gravity sensing system well it's partly a gravity sensing system in the in the sense that gravity is a force that's acting on you as if you were moving through the world in the opposite direction all right now you got to explain that to me okay so basically the idea is that if we leave gravity aside we're just sitting in in a car in the passenger seat and the driver hits the accelerator and you start moving forward you sense that if your eyes were closed you'd sense it if your ears were plugged in your eyes were closed you'd still know it many people take off on the plane like this they're dreading the flight and they know when it's the plane is taking off sure that's your vestibular system talking because anything that jostles you out of the current position you're in right now will be detected by the vestibular system pretty much so this is a complicated system but it's basically in your inner you know ear very close to where you're hearing I think put it there and I don't know I'm just getting there's a to steal our friend Russ van Gelder's explanation we weren't consulted the design phase and no that's a great that's a great line but it's interesting it's in the ear yeah it's yeah it's deep in there and it's served by the same nerve actually that serves the hearing system one way to think about it is both the hearing system and the vestibular self-motion sensing system are really detecting the signal in the same way they're carrying cells and they're excited yeah sort of they got little silly sticking up off the surfaces and depending on which way you bend those the cells will either be inhibited or excited they're not even neurons but then they talked to neurons with a neuron like process and off you go now you've got an auditory signal if you're sensing things bouncing around in your cochlea which is you know sympathetically that bouncing of your eardrum which is in sympathetically the sound waves in the world but in the case of the vestibular apparatus evolution is built a system that detects the motion of say fluid going by those hairs and if you put a sensor like that in a two that's fluid filled now you've got a sensor that will be activated when you rotate that two around the axis that passes through the middle of it those you were just listening won't one people are in some of the other ones I was thinking of it as three who loops right three who's standing up one lying down on the ground right that you know the other one the other way three directions you know the people who fly will talk about roll pitch and y'all that kind of thing so three axes of encoding just like in the call to the rest the no and then I always say it's and then the puppy head toe yeah the puppy head that's the other one so the point is that your your brain is eventually going to be able to unpack what these sensors are telling you about how you disroated your head in very much the way that the three types of cones we were talking about before are reading the incoming photons in the wavelength domain differently and if you agree yeah you can come here and trust you get red mean blue so it's the same basic idea if you have three sensors and you array them properly now you can tell if you're rotating your head left to right up or down that's the sensory signal coming back into your brain confirming that you've just made a movement that you will but what about on the plane because when I'm on the plane I'm completely stationary the planes moving right my head doesn't move right so I'm just moving forward gravity is constant exactly so how do I know I'm accelerating so what's happening now is your brain is sensing the motion and the brain is smart enough also to ask itself did I will that movement or did that come from the outside so now in terms of sort of understanding what the the distributor signal means it's got to be embedded in the context of what you tried to do or what what your other sensory systems are telling you about what's happening I see so that's very interesting I but it's not conscious or at least if it's conscious it's very it not conscious is it's definitely very fast right the moment that plane starts moving I know that I didn't get up out of my chair and run forward right but I'm not really thinking about getting up out of my chair I just know I guess the way I think about it is that the system is quote aware at many levels when it gets all the way up to the cortex and we're thinking about it you're talking about it you know that's cortical but the the lower levels of the brain that don't require you to actually actively think about it there does doing their thing are also made aware right a lot of this is happening under the surface of what you're thinking these are reflexes okay so we've got this gravity sensing system right for you I'm nodding for those are listening for a yes movement of the head and no movement of the head or the tilting of the head from side to side right and then you said that knowledge about whether or not activation of that system comes from my own movements or something acting upon me like the plane moving right has to be combined with other signals and so how is the visual information or information about the visual world combined with balance information right so yeah I mean I guess maybe the best way to think about how these two systems work together is to think about what happens when you suddenly rotate your head to the left when you suddenly rotate your head to the left your eyes are actually rotating to the right automatically you do this in complete darkness if you had an eye or infrared camera and watch yourself in complete darkness you can't see anything rotating your head to the left your eyes would rotate to the right that's your vestibular system saying it's I'm going to try to compensate for the head rotation so my eyes are still looking in the same place why is that useful well if it's always doing that then the image of the world on your retina will be pretty stable most of the time and that actually helps vision have they built us into cameras for image stabilization because when I move when I take a picture with my phone it's blurry it's not it's not clear well actually you know you might want to get a better phone because now what they have is software in the better apps it will do a kind of image stabilization post-hawk by doing a registration of the images that are bouncing around they say this the edge of the house was here so let's get that aligned in each of your images so you may not be aware if you're using a good new phone that if you walk around a landscape and hold your phone that you know there's all this image stabilization going on but it's built into standard cinematic you know technology now because we tried to do a hand hold camera things would be bouncing around things would be unwatchable you wouldn't be able to really understand what's going on in the scene so the brain works really hard to mostly stabilize the image of the world on your retina of course you're moving through the world so you can't stabilize everything but the more you can stabilize most of the time the better you can see and that's why when we're scanning a scene looking around at things we're making very rapid I'm movements for very short periods of time and then we just rest but we're not the only ones that do that if you ever watch a hummingbird does exactly the same thing at a feeder right but it's looking at its body children it's going to make a quick movement and then it's going to be stable and when you watch a pigeon walking on the sidewalk it does this funny head bobbing thing but what is really doing is head back on its neck while its body goes forward so that the image of the visual world stays static is that whether you yes and you've seen the funny chicken videos on YouTube right you take a chicken moving up and down the head stays in one place it's all the same thing all of these animals are trying hard to keep the image of the world stable on the retina as much of the time as they possibly can and then when they've got a move make it fast make it quick and then stable once again that's what you're doing and then you're going to have the image of their head back it is yeah wow yeah I mean I just need to pause there for a second and digest that amazing in case people aren't well there's no reason why people would know what we're doing here but essentially what we're doing is we're building up from sensory you know light onto the eye make color to what the brain does with that the brain of that you know circadian clock militant and now what we're doing is we're talking about multi sensory or multi-modal combining one sense vision with another sense balance right and it turns out the pigeons no more about this than I do because pigeons know to keep their head back as they walk forward right all right so that gets us to this issue of motion sickness right and if you don't have to go out on a boat anytime I go to New York I sit in an Uber or in a cab in the back and if I'm looking at my phone while the car is driving I feel nauseous by time I arrive at my destination right I always try and look out the front of the windshield because I'm told that helps but it's a little tiny window right and I end up feeling slightly less sick if I do that so what's going on with the vision and the balance system that causes a kind of a nausea and actually if I keep talking about the sitting around the look at sick I don't throw up easily but but for some reason motion sickness is a real thing for me it's a problem for a lot of people I mean I think through the fundamental problem typically when you get motion sick is what they call visual vestibular conflict that is you have two sensory systems that are talking to your brain about how you're moving through the world and as long as they agree you're fine so if you're driving you know your body senses that you're moving forward your vestibular system you know is is picking up this acceleration of the car and your visual system is seeing the consequences of forward motion in the sweeping of the scene past you everything is honky dori right no problem but when you are headed forward but you're looking at your cell phone what is your retinus sing your retinus sing the stable image of the screen there's absolutely no motion in that or the motion is or some other motion like a movie or if you're playing a game or you're watching a video a football game you know the motion is uncoupled with what's actually happening to your body your brain doesn't like that your brain likes everything to be you know a line and if it's not it's going to complain to you by making me feel nauseous and maybe you'll change your behavior so you're getting I'm getting punished yeah for for for setting it up so you're a signal so I can flick right by the vestibular you'll learn visuals in time I love it I love the idea of reward signals and we've done a lot of discussion about this on this podcast of things like dopamine reward and things but also punishment signals and I love this example well maybe marching a little bit further along this pathway visual input is combined with balance input where does that occur and maybe because I have some hint of where it occurs you could tell us a little bit about this kind of mysterious little mini brain that they call the cerebellum yeah so you know the way I try to describe the cerebellum to my students is that it serves sort of like the air traffic control system functions in air travel so that it's a system is very complicated and it's really dependent on great information so it's taking in the information about everything that's happening everywhere not only through your sensory systems but it's listening into all the little centers elsewhere in your brain that are computing what you're going to be doing next and so forth so it's just roughness for that kind of information so it really is like a little mini brain it is it's it's got access to all those signals and it really has an important role in in coordinating and shaping movements but you know if you suddenly eliminated the aircraft control system planes could still take off and land but you might have some unhappy accidents in the in the process so the cerebellum is going to like that it's not that you would be paralyzed if your cerebellum was gone because you still have motor neurons you still have ways to talk to your muscles you still have reflex centers and it's not like you would have any sensory loss because you still have your cortex getting all of those beautiful signals that you can think about but you wouldn't be coordinating things so well anymore the timing between input and output might be off or if you were trying to practice a new athletic move like an overhead serve in tennis you'd be just terrible at learning all the sequences of muscle movements and the feedback from your sensory apparatus that would let you really hit that ball exactly where you wanted to after the end rep right now the thousandth rep or something you get much better at it so the cerebellum is all involved in things like motor learning and refining the precision of of movements so that they get you where you want to go if you reach for a glass of champagne that you don't knock it over or stop short people who have selective damage to the cerebellum have salute and what I come familiar with of course a coughs is different right isn't that a B vitamin deficiency from in chronic alcoholics right and they have a they tend to walk kind of bow leg it and they can't coordinate their movements is that that has some that not sure about it also cerebellum I'm not sure about the cerebellum involvement there but you know the typical thing would be a patient who has a cerebellum or stroke or tumor for example might be not that steady on their feet you know if the you know dynamics of the situation is standing on a street car with no pole to hold on to they might not be as good adjusting all the little movements of the car you know this a kind of tremor that can occur as they're reaching for things because they reach a little too far and then they over a correct and come back things like that so it's it's very common neurological phenol and actually cerebellar ataxiates is what the neurologist call it and it can happen not just with cerebellum but damage to the tracks that feed the information into the cerebellum or by the structure exactly or output from the cerebellum and so the cerebellum is where a lot of visual and and balance information is combined in a very key place in the cerebellum which is it's really one of the oldest parts in terms of that the flocculus right this is a it's a critical place in the cerebellum where visual and distributed information comes together recording just the kinds of movements we were talking about this image stabilizing network it's all happening there and there's learning happening there as well so that if your distributor apparatus is a little bit damaged somehow your visual system is actually talking to your cerebellum saying there's a problem here there's an error and your cerebellum is learning to do better by increasing the output of the distributor system to compensate for whatever that loss was so it's a little error correction system that's sort of typical of cerebellar function and it can happen in many many different domains this is just one of the domains of sensory motor integration that takes place there so I should stay off my phone in the ubers if I'm on a boat I should essentially look and as much as possible act as if I'm driving the the machine right that'd be weird if I was in the passenger seat pretending I was driving the machine but I do always feel better if I'm sitting in the front seat passenger right so more of the visual world that you can see as if you were actually the one doing the motion I would think let's stay in the inner ear for a minute as we continue to march around the nervous system when you take off in the plane or when you land or sometimes in the middle of there your ears get clogged or at least my ears get clogged that's because of pressure build up in the various tubes of the inner ear etc. we'll get into this but years ago our good our good friend Harvey Carton is another world class neuronatomist gave a lecture and talked about how plugging your nose and blowing out versus plugging your nose and sucking in can should be done at different times depending on whether or not you're taking off or landing and I always see people trying to unpop their ears right and when you do scuba diving you learn how to do this without necessarily I can do it by just kind of moving my jaw now because it's a little bit of diving but what's the story there we don't have to get into all the differences atmosphere pressure etc but if I'm taking off and my ears are plugged yeah I've recently ascended plane took off my ears are plugged do I plug my nose and blow out or do I plug my nose and suck in right so the basic idea is that if your ears feel bad because you're going into an area of higher pressure so if they pressurize the cabin more than the pressure that you have on the surface of the planet your eardrums will be bending in and they don't like that if you push a more they'll hurt even more that's a good description that you know that pressure goes up then they're going to bend in and then reverse would be true if you go into an area of low pressure so if you you started to drive up the mountain side you know the pressure is getting lower and lower outside now the inside the air behind your your drum is ballooning out right so it's just a question of you know are you trying to get more pressure or less pressure behind the eardrum and there's a little tube that does that and comes down to your you know back your throat there and if you force pressure up that tube you're going to be putting more air pressure into the compartment to counter it if it's if it's not enough and if you're sucking you're going the other way in reality I think as long as you open the passageway I think the different pressure differential is going to solve your problem so I think you could actually blow in when you're not quote supposed to okay so you could just blow your nose and blow air out or hold your nose and suck in the effect either way is fine I think so I think so you just I just won a hundred dollars from our recording thank you very much this is a lot we Harvey nice to teach your anatomy together I'll say I don't think it matters but thank you verse I'll split I'll split that with you okay this is this is important stuff but but it's true you hear this you know so so it doesn't matter either way I'm no expert in this area don't don't quote me he's not going to quote you but okay so we've talked about the inner ear we've talked about the cerebellum I want to talk about an area of the cerebellum is rarely discussed which is the midbrain yeah and for those there don't know the midbrain is an area beneath the cortex I guess we never really defined cortex it was kind of the outer layers or or the outer layers of the least mammalian brain a human brain but the midbrain is super interesting because it controls a lot of unconscious stuff reflexes etc and then there's this phenomenon even called blind site so could you please tell us about the midbrain about what it does and what in the world is blind site yeah so this is a there's a lot of pieces there I think the first thing to say is if you imagine the nervous system in your mind's eye you see this big honking brain and then this little one that dangles down into your vertebral column the spinal cord and that's kind of your visual impression what you have to imagine is starting in the spinal cord and working your way up into this big magnificent brain and what you would do as you enter the skull is get into a little place where the spinal cord kind of thickens out it still has that sort of long skinny trunk like feeling sort of like a paddle or a spoon shape right it starts spread out a little bit that's because your you know evolution is packed more interesting goodies in there for processing information and generating movement so beyond that is this twin brain we were talking about to link this link or brain with dying stuff line really means the between brain oh I thought you said tween well it is yes no no between between the between is the between brain is what the name means it's the linker from the spinal cord in the periphery up to these grand centers of the cortex but this midbrain you're talking about is the last bit of this enlarged sort of spinal cordy thing in your skull which is really the brain stem is what we call it the last bit of that before you get to this relay up to the cortex is the midbrain and there's a really important visual center there it's called the superior colliculus there's a similar center in the brains of other vertebrate animals a frog for example or a lizard would have this is called the optic tectum there but it's a center then in these non mammalian vertebrates is really the main visual center they don't really have what we would call a visual cortex although there's something sort of like that but this is where most of the action is in terms of interpreting visual input and organizing behavior around that you can sort of think about the this region of the brain stem is a reflex center that can reorient the animals gaze or body or maybe even attention to particular regions of space out there around the animal and that could be all for all kinds of reasons I mean it might be a predator just showed up in one corner of the forest and you picked that up and you're trying to avoid it or just any movement many movement right it might be you know that's suddenly you know something splats on the page when you're reading a novel and your eye reflexly looks at it you don't have to think about that that's a reflex what if you throw me a ball but I'm not expecting it and I just reach up and and try and grab it catch it or not right is that handled by the midbrain well that's probably not the midbrain although it I mean by itself because it's going to involve all these limb movements this movement of your arm and body what about ducking and probably thrown in the head sure right things like that are will certainly have a brain stem component a midbrain component you know something looms and you duck it may not be the superior colliculus we're talking about now might be another part of the visual midbrain but these are centers that emerged early in the evolution of brains like hours to handle complicated visual events that have significance for the animal in terms of space where is it in space and in fact the same center actually gets input from all kinds of other sensory systems that take information from the external world from particular locations and where you might want to either avoid or approach things according to their significance to you so you get input from the touch system you get input from the auditory system I work for a while in rattlesnakes they get input from a part of their warm sensors on their face they're in these little pits on the face work on baby rattlesnakes right well they were they were adults I wasn't trying to diminish the danger I thought for some reason they were little ones no why in the world would you work on rattlesnakes well because they have a version of an extra-acceptive sensory system that is they're looking out into the world using a completely different set of sensors they're using the same sensors that would feel the warmth on your face if you stood in front of a bonfire except evolution is given them this very nice specialized system that lets them image where the heat's coming from you can sort of do that anyway right if you walk around the fire you can feel which where the fire is from the you know the heat hitting your face is that the primary way in which they detect prey it's one of one of the major ways and in fact they use vision as well and they bring these two systems together in the same place in this tactile region this brain stem they bring the tongue-judding about when that snakes that I don't know that maybe old factory they're maybe they're sniffing the air with their tongue yeah there may be a good way to drive you told me that flies actually taste things with their feet they do yeah yeah so yeah they have they have taste receptors in lots of funny places I I want to pause here just for one second before we get back into the midbrain I think what's so interesting in all seriousness about taste receptors on feet heat sensors tongue-judding out of snakes and vision and all this integration is it really speaks to the fact that all these sensory neurons are trying to gather information right and stuff it into a system that can make meaningful decisions and actions and that it really doesn't matter whether or not it's coming from eyes or ears or nose or bottoms of feet because in the end it's just electricity flowing in and so it's it sounds like it's placed on each animal it's always feels weird to call fly an animal but they are features they are animals it's placed in different locations on different animals depending on the particular needs of that animal right but how much more powerful if the nervous systems can also cross correlate across sensory systems so if you've got a weak signal from one sensory system you're not quite sure there's something there and a weak signal from another sensory system that's telling you the same locations is a little bit interesting there might be something there if you've got those two together you've got corroboration your brain now says it's much more likely that that's going to you know be something worth paying attention to right so maybe I'm feeling some heat on one side of my face and I also smell something baking in the oven right so now there's it's neither is particularly strong but as you said there's some corroboration right and that corroboration is occurring in the midbrain right and then if you throw things into conflict now the brain is confused and that maybe where your your motion sickness comes from so it's great to have you know as a as a brain it's great to have as many sources of information as you can have just like if you're you know you're you're a spy or a journalist you know one is much information as you can get about what's out there but if things conflict that's problematic right your sources are giving you different information about what's what's going on now you've got a problem on your hands what do you publish the midbrain is so fascinating I don't want to eject us from the midbrain and go back to the vestibular system but I do have a question that I forgot to ask about the vestibular system which is why is it that for many people including me there's a despite my motion sickness and calves that there's a sense of pleasure in moving through space and getting tilted relative to the gravitational pull of the earth for me growing up it was skateboarding but people like to corner in cars corner on bikes it may be for some people it's done running or dance but you know what is it about moving through space and getting tilted a lot of surfers around here getting tilted that can tap into some of the pleasure center so do we have any idea why that would feel I have no clue is their dopaminergic input to this system well you know the dopaminergic system gets a lot of places you know it's pretty much to some extent everywhere in the cortex a lot more in the front of the lobe of course but you know that's just for starters I mean there's basically dopaminergic innervation most places in the central nervous system so there's the potential for dopaminergic involvement but I really have no clue about the tilting phenomenon I mean people pay money to go on roller coasters right well I think that maybe is much about the thrill is anything sure and falling is the falling reflexes very robust in all of us right the visual world's going up very fast it really means that we're falling right right but in some people like that some people don't right and kids kids tolerate a lot more you know sort of the distributor craziness spinning around until they drop and I've friends it always you know worries me a little bit that will they throw their kids I'm not recommending anyone do this when they're low kids you know like throwing the kids really far back and forth kids some kids seem to love it yeah yeah our son loved being shaken up and down very very vigorously that's the only thing that would calm down sometimes interesting yeah so I'm guessing we can we can guess that maybe there's some activation of the reward systems from yeah being moving moving through space well that mean if you think about you know how rewarding it is to be able to move through space and how unhappy people are who are used to that who suddenly aren't able to do that there is a sense of agency right if you you can choose to move through the world and to tell that's not only you're moving through the world but you're doing with a certain amount of finesse maybe that's what it is you can feel like you're the master of your own movement in a way that you wouldn't if you're going straight I'm just blowing smoke here yeah well we can speculate that's fine I couldn't help but ask the question okay so if we move ourselves on intended back into the midbrain the midbrain is combining all these different signals for reflexive action at what point does this become deliberate action because if I look at something I want and I want to pursue it I'm going to go toward it and many times that's a deliberate decision right so this gets very slippery I think because what you have to try to imagine is all these different parts of the brain working on the problem of staying alive you know and surviving in the world they're working on the problem simultaneously and there's not one right answer to how to do that but the one way to think about it is that you have high levels of your nervous system that are very well designed to override and otherwise automatic movement if it's inappropriate so if you imagine you've been invited to tea with the queen and she hands you you know very fancy wedge wood you know teacup very thin wedge wood teacup yes with very hot tea in it and you're burning your hand you probably will try to find a way to put that back down on the saucer rather than just dropping it on the floor because you're with the queen you know you're trying to be appropriate to that so you have ways of reigning in automatic behaviors if they're going to be maladaptive but you also want the reflex to work quickly if it's the only thing that's going to save you the looming you know object coming at your head you don't have time to think about that so this is the interplay in these hierarchically organized centers of the nervous system at the lowest level you've got the automatic behavior in the center and the center is in reflux you know arcs that will keep you safe even if you don't have time to think about it and then you've got the higher center saying well maybe we could do this as well or maybe we shouldn't do that at all right so you have all of these different levels operating simultaneously and you need bi-directional communication between high level cognitive centers decision making on the one hand and these low level very helpful reflexive centers but they're a little bit rigid a little hard wired so they need some nuance so there's both of these things are operating in tandem in real time all the time in our brains and sometimes we listen more to one than the other you've for people in sports talking about messing up at the play because they over thought it you know thinking too hard about it that's partly you've already trained your cerebellum had a fastball right down the middle right and if you start looking for for something new or different you're going to mess up your your reflexive swing right if you're trying to think about the physics of the ball as it's coming at you you've already missed right you know because you're not using your all those reps have built a kind of knowledge is what you want to rely on when you don't have enough time to contemplate this is important and a great segue for what I'd like to discuss next was it which is the basal ganglia this really interesting of the area the brain that's involved in go type commands and behaviors instructing us to do things and no go preventing us from doing things so much of motor learning and skill execution and not saying the wrong thing or sitting still in class when or as you use with the you know T with the queen example feeling discomfort involves suppressing behavior and sometimes it's activating behavior right you know tremendous amount of online attention is devoted to trying to get people motivated you know this isn't the main focus of our podcast we touch on some of the underlying neural circuits of of motivation dopamine and so forth but so much of what people struggle with out there are elements around failure to pay attention or challenges in paying attention which is essentially putting the blinders on there you know getting a so-disdraw view of the world and maintaining that for a bout of work or something of that sort and trying to get into action so of course this is carried out by many neural circuits not just the basal ganglia but what are the basal ganglia and what are their primary roles in controlling go type behavior and no go type behavior yeah so I mean the basal ganglia are sitting deep in what you would call the four brains or the highest levels of the brain they're sort of cousins to the cerebral cortex which we talked about is sort of the highest level of your brain that the thing you're thinking with cerebral cortex being the refined cousins and then you've got the right you know the brute yeah I mean that's probably totally unfair but that's all right I like the basal ganglia I can relate to the British parts of the brain a little bit of hypothalamus a little bit of basal ganglia sure we need it all we need it all and you know this area of the brain has gotten a lot bigger as the cortex has gotten bigger and it's deeply intertwined with cortical function the cortex can't really do what it needs to do without the help the basal ganglia and vice versa so they're really intertwined and in a way you can think about this logically is saying you know if you have the ability to withhold behavior or to execute it how do you decide which to do well the cortex is going to have to do that thinking for you you have to be looking at all the contingencies of your situation decide is this a crazy move or is this a really smart investment right now or you know what I don't want to go out for a run in the morning when I'm going to make myself go out for a run or I'm having a great time out on a run and I know I need to get back but I kind of want to go another mile I mean another great example is that you know at the marshmallow test for the little kids you know they can get to marshmallows if they hold off you know just 30 seconds initially you know they can have one right away but if they can wait 30 seconds they got to you know so that's the no go because their cortex is saying you know I really like to have two more than having one but they're not going to get the two unless they can not reach for the one so they've got to hold off the action and that has to result from a cognitive process so the cortex is involved in this in a major way. Yeah as I recall in that experiment the kids used a variety of tools to do some would distract themselves I particularly related to the kid that would just put himself right next to the marshmallows and then would and then some of the kids cover their eyes some of them would count or sing yeah so that's all very cortical right coming up with a novel strategy simple example that we're using here but of course this is at play anytime someone decides they want to go watch a motivational speech or something just you know Steve Jobs commencement speech just to get motivated to engage in their day. Sure I take this new job you just got great benefits but it's an allows you part of the country. Why do you think that some people have a harder time running these go-no-go circuits and other people seem to have very low activation energy we would say they can just you know you they have a task they just lean into the task whereas some people getting into task completion or things that sort is very challenging for them. Yeah I mean I think it's really just another it's a special case of a very general phenomenon which is brains are complicated and brains we have are the result of genetics and experience and my genes are different from your genes and my experiences are different from your experiences so the things that are be easier hard for us won't necessarily be aligned they might just happen to be just because they are but the point is that you know you your Delta certain set of cards you have certain set of genes you are handed a you know a brain you don't choose your brain it's handed to you but then there's all this stuff you can do with it you know you you can learn to do you know to have new skills or to act differently or to show more restraint which is kind of relevant to what we're talking about here or maybe show less restraint if your problem is you're so buttoned down you never have any fun in life and you should loosen up a little bit right. Thank you I appreciate the insult yeah David's always encouraging me to have a little more fun so Basil Ganglia are they're kind of the disciplinarian or they there's sort of the instructor conductor of sorts right go no go you know you'd be quiet you start now I wish I knew more about the Basil Ganglia than I then I do my sense is that it you know this system is key for implementing the plans that yet cooked up in the cortex but they also influence the plans that the you know cortex is is dishing out because this is a major source of information to the cortex so it becomes almost impossible to figure out where the computation begins and where it ends and who's doing what because these things are all interacting in a complex network and it's all of it it's the whole network it's not you know one is the leader and the other is the follower of course yeah these are all the structures that we're discussing are working in parallel right and there's a lot of changing crosstalk I have this somewhat sick habit David of every day I try and do 21 no goes so if I want to reach for my phone I try and not do it just to see if I can prevent myself from engaging in that behavior if it was reflexive it's something I want to do deliberate choice then I certainly allow myself to do it right I don't tend to have too much trouble with motivation with go type functions most of you because I'm so busy that I wish I had more time for more goes but so to speak but do you think these circuits have genuine plasticity and absolutely I mean everybody knows how they've learned over time to wait for the two marshmallows right you know you don't have to have instant gratification all the time you know what you're willing to do a job sometimes it isn't your favorite job because it comes with a territory and you want the salary that comes at the end of the week or at the end of the month right so we can defer gratification you know we can choose not to say the thing that we know is going to inflame our partner and create a you know a meltdown for the next week you know we we learn this control but I think these are skills like any other you can get better at them if you practice them so I think you're choosing to do that dysphantaneously as kind of a you know it's a mental practice it's a discipline it's a way of building a skill that you want to have yeah I find it to be something that when I engage in a no go type situation then the next time and the next time that I find myself about to move reflexively there's a little gap in consciousness that I can inter I can make a decision whether not this is really the best use of my time because I I sometimes wonder whether not all this business around attention certainly there's the case of ADHD and clinical diagnosed ADHD but all these the issue around focus and attention is really that people just have not really learned how to short circuit a reflex and so much of what makes us different than rattlesnakes or well actually they could be deliberate but from the other animals and is our ability to suppress reflex yeah well that's the cortex and let's say the four brain cortex and basal ganglia working together sitting on top of this lizard brain that's giving you all these great adaptive reflexes that help you survive you just hope you don't get the surprising case where the thing that your reflex is telling you is actually exactly the wrong thing and you make a mistake right and that's right right so that's what the cortex is for it's adding nuance and context and experience past association and in human beings obviously learning from others through you know communication well I was you went right to it and it was where I was going to go so let's talk about the cortex we've worked our way up the so-called Neuraxis as the Fisiinados will know so we're in the cortex this is the seat of our higher consciousness self-image planning and action but as you mentioned the cortex isn't just about that it's got other regions that are involved in other things so maybe we should staying with vision let's talk a little bit about visual cortex you told me a story an amazing story about visual cortex and it was a somewhat of a sad story unfortunately about someone who had a stroke to visual cortex maybe you would share that story because I think it illustrates many important principles about what the cortex does. Right so you know the visual cortex is you could say the projection screen the first you know place where this information streaming from the retina through this valumus you know connecting linker gets played out for the highest level of your brain to see I mean so representation it's a map of things going on in the visual world that's in your brain and when we describe a scene to a friend we're using this chunk of our brain to be able to put words which are coming from a different part of our cortex to the objects and movements and colors that we see in the world so you know that's a key part of your visual experience when you when you can describe the things you're seeing you're looking at your visual cortex and this is good I just had a quick question so right now because I'm looking at your face right as we're talking there are neurons in my brain more or less in the configuration of your face that are active as you move about and what if I were to close my eyes and just imagine did I do this all the time by the way David I close my eyes and I imagine David Berson's face I don't tend to do that as often maybe I should but you get the point I'm I'm now using visualization of what you look like by way of memory right if we were to image the neurons in my brain would the activity of neurons resemble the activity of neurons that's present when I open my eyes and look at your actual face this is a deep question we don't really have full accounts for them to do it yes except you know you're talking about looking in detail at the activity of neurons in a human brain and that's not as easy to do is as it would be in a you know some kind of animal model but you know the bottom line is that you you have a spatial representation of the visual world late as a map of the visual world laid out on the surface of your cortex the thing that's surprising is that it's not one map it's actually dozens of maps what are each of those maps do well we don't really have a full accounting there either but it looks a little bit like the diversification of the different neurons of the retina the ganglion cells we were talking about before there are different types of ganglion cells that are encoding different kinds of information about the visual world we talk about the ones that were encoding the brightness but other ones are encoding motion or color these kinds of things the same kinds of specializations in different representations of the visual world in the cortex seem to be true it's a complex story we don't have the whole the whole picture yet but it does come parts of the brain are much more important for things like reaching for things in the space around you and other parts of the cortex are really important for making associations between particular visual things you're looking at now and their significance what they what what is that object what can it do for me how can I use it what about the really specialized areas of cortex like the areas like neurons that respond to particular faces or neurons that I don't know can help me understand where I am relative to some other specific object right so you know this these are our properties of neurons that are extracted from detected by recording the activity of single neurons in some experimental system what's going on when you actually perceive your grandmother's space is a much more complicated question and he clearly involves hundreds and thousands and probably millions of neurons acting in a cooperative way so you can pick out any one little element in this very complicated system and see that it's responding differentially to certain kinds of visual patterns and you think you're seeing a glimpse of some part of the process by which you recognize your grandmother's face but that's a long way from a complete description and it certainly isn't going to be at the level of a magic single neuron that has the special stuff to recognize your grandmother it's going to be in some pattern of activity across many many cells resonating in some kind of special way that will represent the internal you know memory of your of your mother so it was really incredible yeah I mean that I mean that every time we do this deep dive which we do from time to time you and I we kind of like march into the nervous system and explore how different aspects of our of our life experiences is handled there and how it's organized the it after so many decades of doing this it still boggles my mind that that the collection of neurons one through seven active in a particular sequence gives the memory of a particular face and run backwards seven through to one gives you a complete you know could be you know rattlesnake paper heat sensing organs right we were talking about earlier so it sounds is it true that there's a lot of multi-purposing of the circuitry like we can't say one area of the brain does a and another area the brain does be so you know areas can multitask or have multiple jobs they can moonlight right but I I think in my career the hard problem has been to square that with the fact that you know things are specialized that there are specific genes expressed in specific neurons that make them make synaptic connections with only certain other neurons and that particular synaptic arrangement actually results in the processing of information that's useful to the animal to survive right so it's not as if it's either a big undifferentiated network of cells and looking at any one is never going to tell you anything that's too extreme on the one hand nor is it the case that everything is hardwired and every neuron has one function and this all happens in one place in the brain it's way more complicated and interactive and interconnected than that so we're not hardwired or softwired we're sort of I don't know what the analogy should be what what substance would work best David no idea there but you know the idea is that it's always network activity there's always many many neurons involved and yet there's tremendous specificity in the neurons that might or might not be participating in any distributed function like that right so you have to get your mind around the fact that it's both very specific and very non-specific at the same time it's a little tricky to do but I think that's kind of where the truth lies yeah and so the the same thing is so the this example that you mentioned one to me once before about a woman who had a stroke in visual cortex I speak to some of this right could you share with us that story sure so the point is that you all those of us who see have representations of the visual world in our visual cortex what happens to somebody when they become blind because of problems in the eye the retina perhaps you have a big chunk of the cortex is really valuable real estate for neural processing that has come to expect input from the visual system and there isn't any anymore so you might think about that as fallow land right it's just it's unused by the nervous system and that would be a pity but it turns out that it isn't in fact used and the case that you're talking about is of a woman who was blind from very early in her life and who had risen through the ranks to a very high level executive secretary position in a major corporation and she was extremely good at rail reading and she had a braille typewriter and that's how everything was done and apparently she had a stroke and was discovered at work collapse and it brought to the hospital and apparently the neurologist who saw her when she finally came to said you know I've got good news and bad news bad news is he had a stroke the good news is that it was in an area of your brain you're not even using it's your visual cortex and I know you're blind from birth so there shouldn't be any issue here the problem was she lost her ability to read braille so what appears to have been the case and this has been confirmed in other ways by imaging experiments in humans is that in people who are blind from very early in birth the visual cortex gets repurposed as a center for processing tactile information and especially if you drain to be a good braille reader you're actually reallocating somehow that real estate to your fingertips you know a part of the cortex that should be listening to the eyes so that's an extreme level of plasticity but what it shows is the visual cortex is kind of a general purpose processing machine is good at spatial information and the skin of your fingers is just another spatial sense and deprived of any other input the brain seems smart enough if you want to put it that way to rewire itself to use that real estate for something useful in this case reading braille incredible somewhat tragic but incredible at least in that case tragic very informative and of course it can go the other way too where people can gain function in particular modalities like improved hearing or tactile function in the absence of vision right tell us about connect homes we hear about genomes proteomes microbiomes homes homes these days what's a connect home and why is it valuable yeah so so connect home actually now has two meanings so I've only referred to more the one that is my passion right now and that is really trying to understand the structure of nervous tissue at a scale that's very very fine smaller than a millimeter way smaller than a millimeter a or less as that's a thousand times smaller or it's actually you know a million times smaller so really really tiny on the scale of individual synapses between individual neurons or even smaller like the individual synaptic vesicles containing little packets of neurotransmitter they're going to get it released to allow one neuron to communicate to the next so very very fine but the the notion here is that you're doing this section after section at very fine scale so in theory what you have is a complete description of a chunk of nervous tissue that is so complete that if you took enough time to identify where the boundaries are all the cells are you could come up with a complete description of the synaptic wiring of that chunk of nervous tissue because you have a complete description of where all the cells are and where all the synapses between where all the cells are so now you essentially have a wiring diagram of this complicated piece of tissue so the omics part is the exhaustiveness of it rather than looking at a couple of synapses that are interesting to you from two different cell types you're looking at all the synapses of all of the cell types which of course is this massive avalanche of data right so in genetics you have genetics and then you have genomics which is the idea of getting the whole genome all of it and we don't really have an analogous word for genetics but it would be connectivity and kinomics right I can't excuse me I'm conic tommy conic tommy so it's it's wanting at all and of course it's crazy ambitious but you know that's that's where it gets fun you know it's really it's a use of electron microscopy a very high resolution microscopic imaging system on a new scale with way more payoff in terms of understanding the connectivity of the nervous system and it's just emerging but I really think it's going to revolutionize the field because we're going to be able to query these circuits how they actually do it look at the hardware in a way that's never been possible before the the way that I describe this to people is if you were to take a chunk of kind of cold cooked but cold spaghetti right and slice it up very thin you're trying to connect up each image of each slice of the edge of the spaghetti as figure out which ropes of spaghetti belong to which and have a complete description of where this piece of spaghetti touches that piece of spaghetti there's there's something special there obviously it's also isn't all the other cell types and the the the pesto you know all where it all is around the spaghetti those are the other cell the blood vessels and the glial cells and so what's it good for I mean maps are great right I always think of connectomics and genomics and proteomics etc as necessary but not sufficient right right so I mean in many cases what you do is you go out and probe the the function and you understand how the brain does the function by finding neurons that seem to be firing in association with with this function that you're observing and little by little your work your way in and now you want to know what the connectivity is maybe the anatomy could help you but this connectomics approach or at least the serial electron microscopy reconstruction of neurons approach really is allowing us to frame questions starting from the anatomy and saying I see a synaptic circuit here my prediction would be that these cell types would interact in a particular way is that right and then you can go and probe the physiology and you might be right or you might be wrong but more often than not it looks like the structure is pointing us in the right direction so in my case I'm using this to try to understand a circuit that is involved in this image stabilization network we're talking about keeping things stable on the retina and this thing will only respond at certain speeds of motion these these cells in the circuit like slow motion they won't respond to fast motion how does that come about well I was able to probe the circuitry I knew what my cells looked like I could see which other cells were talking to it I could categorize all the cells that might be the players here that are involved in this mechanism of tuning the thing for slow speeds and then we said it looks like it's that cell type and we went and looked and the data bore that up but the anatomy drove the cell type because we could see it connected in the right place to the right cells so that creates the hypothesis that's you go query the physiology but it can go the other way as well so it's always the synergy between these functional and structural approaches it gives you the most lift but you know in many cases the anatomy has been a little bit the weak sister in this the structure trying to work out the diagram because we haven't had the methods now the methods exist and we know the methods exist and this whole field is expanding very quickly because people want these circuit diagrams for the particular part of the nervous system that they're working on if you don't know the cell types and the connections how do you really understand how the machine works yeah what I love about is we don't know what we don't know and scientists we don't ask questions we pose hypotheses hypotheses being of course some some prediction that you wager your time on basically right and it either turns out to be true or not true but if you don't know that a particular cell type is there you could never in any configuration of life or a career or exploration of a nervous system wager a hypothesis because you didn't know it was there so this allows you to say ah there's a little interesting little connection between this cell that I know is interesting in another cell that's a little mysterious but interesting I'm going to hypothesize that it's doing blank blank and blank and go test that and in the absence of these connect homes you would never know that that cell was lurking there in the shadows right right yeah and if you just trying to understand how information flows through this biological machine you want to know where things are you know the neurotransmitters are dumped out of the terminals of one cell and they diffuse across the space between the two cells which is kind of a liquid space and they get some receptors on the post-naptic cell and they have some impact sometimes that's not through a regular synapse sometimes it's through a neuromodulator like you often talk about on your podcast that are sort of using exactly losing into the space between the cells and it may be acting at some distance far from where it was released right but if you don't know where the releases happening and where other things are that might respond to that release you're cropping around in the dark well I love that you are doing this and I have to share with the listeners that at the first time I ever met David and every time I've ever met with him in person at least at his laboratory at Brown he was in his office door closed drawing neurons and their connections and this is somewhat unusual for somebody who's a you know endowed full professor of chairman the department etc for many years to be doing the hands-on where typically that's the stuff that's done by technicians or graduate students or postdocs but I think it's fair to say that you really love looking at nervous systems and drawing the accurate renditions of how those nervous systems are organized and thinking about how they work yeah it's pure joy for me I mean I'm a very visual person my wife is an artist we look a lot of art together just the forms of things are are gorgeous in their own way but to know that the form is in a sense the function that they that the architecture of the connectivity is how the computation happens in the brain at some level even though we don't fully understand that in most context gives me you know great joy because I'm working on something that's both visually beautiful but also deeply beautiful in it sort of a higher sort of knowledge context you know what is it what is it all about love it well as a final question I get asked very often about how people should learn about neuroscience or how they should go about pursuing maybe an education in neuroscience if they're at that stage of their life or that's appropriate for their current trajectory do you have any advice to young people old people anything in between about how to learn about the nervous system more maybe in a more formal way I mean obviously we have our podcast there are other sources of neuroscience information out there but for the young person who things they want to understand the brain they want to learn about the brain what should we tell them well that's a great question and there's so many sources out there it's almost a question of you know how do you deal with this avalanche of information out there I mean I think your podcast is a great way for people to to learn more about the nervous system in an accessible way but there's so much stuff out there and it's it's not just that I mean the resources are becoming more and more available for average folks to participate in neuroscience research on some level there's this famous iWire project of Sebastian you tell us about iWire yeah so that's connect to a mix and that's a situation where a very clever scientist realized that the physical work of doing all this reconstruction of neurons from these electron micrographs there's a lot of time involved many many person hours have to go into that to come up with the map that you want of where the cells are and he was very clever about setting up a context in which he could crowdsource this and people were interested in getting a little experience looking at nervous issue and participating in a research project could learn how to do this and do a little bit from their living room from their living room there was a little bit of link to iWire that's a it also is a great bridge between what we were just talking about connect to them actually participating in research and you don't need a graduate mentor or or anything like that right so more of this is coming and i'm actually interested in building more of this so that people who are interested want to participate at some level don't necessarily have the time or resources to get involved in laboratory research can can get exposed to it and participate and actually contribute to that so i think that's you know one one thing i mean just asking questions of the people around you who know a little bit more and have them point you in the right direction here's a book you might like to read there's lots of great popular books out there that are accessible that will give you some more sense of the full range of what's out there in the neurosciences and how we can put some links to a few of those that we like right on basic neuroscience right good friend Dick Masland the late Richard people call them Dick Maslin had a good book i forget the title at the moment i'd say sitting behind me somewhere over there on the shelf but about vision and how nervous systems work out a pretty accessible book for the general public right yeah right so you know that and you know there's so many sources out there I mean Wikipedia is a great way if you have a particular question about visual function i would say biomeans you know had to Wikipedia and get the first look and follow the references from there or go to your library or you know there's so many ways to get into it it's such an exciting field now there's so many any particular realm that's special to you your experience your you know your strengths your passions there's there's a field of neuroscience devoted to that you know if you've got if you know somebody who's got a neurological problem or a psychiatric problem there's a branch of neuroscience that is devoted to trying to understand that and to solve these kinds of problems down the line so feel the feel the buzz it's an exciting time to to get involved great those are great resources that people can access from anywhere zero cost as you need an internet connection but aside from that we'll put the links to some and I'm remembering dick's book is called We Know It When We See It Right One of my heroes yeah a wonderful colleague who unfortunately we lost a few years ago but listen David this has been wonderful wonderful we really appreciate you taking the time to do this is people probably realize by now you're an incredible wealth of knowledge about the entire nervous system today we just hit this top contour of a number of different areas to give a flavor of the different ways that the nervous system works and is organized and how that's put together how these areas are talking to one another what I love about you is that you're such an incredible educator and I've taught so many students over the years but also for me personally as friends but also anytime that I want to touch into the the beauty of the nervous system I rarely lose touch with it but anytime I want to touch into it and start thinking about new problems and ways that the nervous system is doing things that I hadn't thought about I call you so I've please forgive me for the calls past present and future unless you change your number and even if you do I'll be calling it's such a blast any you know this has been a great session and it's always fun talking to you is always gets my brain racing so thank you thank you thank you for joining me today for my discussion with Dr. David Berson by now you should have a much clear understanding of how the brain is organized and how it works to do all the incredible things that it does if you're enjoying and or learning from this podcast please subscribe to our YouTube channel that's zero cost way to support us in addition please subscribe to our podcast on Apple and Spotify and on Apple you have the opportunity to leave us up to a five star review as well if you'd like to make suggestions for future podcast episode topics or future podcast episode guests please put those in the comment section on our YouTube channel please also check out our sponsors mentioned at the beginning of each podcast that's the best way to support us and we have a Patreon it's patreon.com slash Andrew Huberman there you can support us at any level that you like while today's discussion did not focus on supplements many previous podcast episodes include discussions about supplements and while supplements aren't necessary for everybody many people derive benefit from them for things like sleep or focus or anxiety relief and so on one issue with the supplement industry however is that oftentimes the quality will really vary across brands that's why we partnered with Thorne TH or I need because Thorne supplements are of the absolute highest standards in terms of the quality of the ingredients include and the precision of the amounts of the ingredients they include in other words what's listed on the bottles what's actually found in the bottle which is not true of many supplements out there that have been tested if you'd like to see the supplements that I take you can go to Thorne.com slash the letter U slash Huberman and there you can see the supplements that I take and you can get 20% off any of those supplements and if you navigate deeper into the Thorne site through that portal Thorne.com slash the letter U slash Huberman you can also get 20% off any of the other supplements that Thorne happens to make if you're not already following Huberman lab on Instagram and Twitter feel free to do so both places I regularly post short video posts or text posts that give tools related to health and neuroscience and so forth and most of the time that information is not overlapping with the information on the podcast again is just Huberman lab on Instagram and Twitter and last but not least thank you for your interest in science.