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. Eddie Chang. Dr. Eddie Chang is the chair of the neurosurgery department at the University of California at San Francisco. Dr. Chang's clinical group focuses on the treatment of movement disorders including epilepsy. He is also a world expert in the treatment of speech disorders and relieving paralysis that prevents speech in other forms of movement and communication. Indeed his laboratory is credited with discovering ways to allow people who have fully locked in syndrome that is who cannot speak or move to communicate through computers and AI devices in order to be able to speak to others in their world and understand what others are saying to them. It is a truly remarkable achievement that we discussed today in addition to his discoveries about critical periods which are periods of time during one's life when one can learn things in particular languages with great ease as opposed to later in life. And we talk about the basis of things like bilingualism and trilingualism. We talk about how the brain controls movement of the very muscles that allow for speech and language and how those can be modified over time. We also talk about stutter and we talk about a number of aspects of speech and language that give insight into not just how we create this incredible thing called speech or how we understand speech and language but how the brain works more generally. Dr. Chang is also one of the world leaders in bioengineering that is the creation of devices that allow the brain to function at super physiological levels and that can allow people with various syndromes and disorders to overcome their deficits. So if you are somebody who is interested in how the brain works normally, how it breaks down and how it can be repaired. And if you are interested in speech and language reading and comprehension of information of any kind, today's episode ought to include some information of deep interest to you. Dr. Chang is indeed the top of his field in terms of understanding these issues of how the brain encodes speech and language and create speech and language. And as I mentioned, movement disorders and epilepsy. We even talk about things such as the ketogenic diet, the future of companies like neural link, which are interested in bioengineering and augmenting the human brain and much more. One thing that I would like to note is that in addition to being a world class neuroscience researcher and world class clinician neurosurgeon and chair of neurosurgery, Dr. Eddie Chang has also been a close personal friend of mine since we were nine years old. We attended elementary school together and we actually had a science club when we were nine years old, focus on a very particular topic. You'll have to listen into today's episode to discover what that topic was and what membership to that club required. That aside, Dr. Chang is an absolute phenom with respect to his scientific prowess that is both his research and his clinical abilities. And he's one of these rare individuals that whenever he opens his mouth, we learn. 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. And now, for my discussion with Dr. Eddie Chang. Eddie, welcome. Hi, I'm Andrew. Great to be here with you. This has been a long time coming. Just to come clean, we've known each other since we were nine years old. Yeah. But then there was a long gap in which we didn't talk to one another. I heard things about you and presumably you heard a thing about me for better or for worse. And then we reconnected years later when I was a PhD student and you were a medical student. We literally ran into each other in the halls of University of California San Francisco, where you're now the chair of neurosurgery. So it all comes full circle. When you were at UCSF, you were working with Mike Merzenick. And I know that name might not be familiar to a lot of people, but he's sort of synonymous with neuroplasticity, the ability of the brain and nervous system to change in response to experience. So for our listeners, I would just love for you to give a brief overview of what you were doing at that time, because I find that work so fascinating. And it really points to some of the things that can promote and maybe hinder our brains ability to change. Oh, wow. That's fantastic. So we did bump into each other serendipitously back then. And at the time I was a medical student at UCSF studying with Mike Merzenick. In particular, I was studying how the brain organizes when you have patterns of sound. And in particular, we were studying the brain of rodents and trying to understand how different sound patterns organize the frequency representation from low to middle of the high frequency maps in the brains of baby rodents. And one of the things that I was very interested in was trying to understand how the patterns of the natural environment, let's say the vocalizations of the environment that the rat pups were raised in or just the natural sounds that they hear how that shapes the structure of the brown of the brain. And one of the things we did was to try and experiment where we raised some of these rat pups and white noise continuous white noise that was essentially masking all of those environmental sounds. And what was the consequence of animals being raised in white noise environment? Well, what are the things that we didn't expect, but we found which is quite striking is that there's this early period in brain development where we're very susceptible to the patterns that we hear or see in neuroscience we call this a critical period or a sensitive period. And we have this for our eyes, but we also have it for our ears and one of the most striking examples of this is that any human can essentially grow up in a culture where they hear different speech sounds from one language to another. And it's like after a couple of years you lose sensitivity to sounds that are not part of your native language and you have high sensitivity for for the languages of your native culture and that's pretty pretty extraordinary that human brain has that flexibility yet at the same time has that specialization for language. And so we were trying to think about how do we model this for example in rodents who obviously don't speak, but we're just understanding how sounds and environmental sounds modulate and organize auditory cortex and one of the things that we found that was quite striking was that if you basically mask environmental sounds from these rat pups. The critical period this sensitive period where it's open to plasticity it's open to change it's open to reorganization that actually that window can stay open much much longer and in one way it sounds like that's good thing but on the other hand it's also a retardation it's actually it slowed the maturation of auditory cortex it was ready to close when these repups were really young but by raising them in white noise we found out that you could keep up with that. And so I think one of the things that taught me was that it's not just about the genetic programming that specifies some of this sensitive period but it's also a little bit about the nature of the sounds that we hear that help keep that window for the critical period open and closed. And I know it's difficult to make a direct leap from animal research to human research but if we could speculate a little bit I can imagine that some people grow up in homes where there's a lot of shouting and a lot of inflection maybe people are very verbose. Others grow up in a home where it's quieter and more peaceful. Some people are going to grow up in cities and just came back from New York City is like all night long there's honking and sirens and it's just non stop and then I return here where it's quite quiet at night. Can we imagine that the human brain is going to be shaped differently depending on whether or not when it grows up in one environment or another and would that impact their tendency to speak in a certain way as well as hear in a certain way what do we know about that well I think that it's from my perspective it's really clear that those sounds that we are exposed to from the very early very early as time even in utero in the womb where the sound is hearing the mother of the mother of the mother. Hearing the mother or father of friends around while in the womb actually will influence how these things organize and and so there's no question that the sounds that we hear are going to have some influence and those sounds are going to structure the way that those neural networks actually lay down and well forever influence how you hear sounds and speech and languages is probably one of the most profound examples of that. I get a lot of questions about the use of white noise during sleep in particular people want to know whether or not using a white noise machine or a machine or a program that makes the sound of waves for instance if it assists their infant and sleeping is it going to be bad for them because it's flooding the auditory system with a bunch of essentially white noise or disorganized noise we have an answer to that question. Not yet I think that what you're asking is really important question because parents are using white noise generators almost universally now and for good reasons you know it is hard to have kids up and night I've got three kids of my own and was very tempted to think about how to use some of these tools to just sue them and get them to bed especially when I was like so tired and exhausted. But I think that there is a cost you know to think a little bit about you know we're not exposed to continuous white noise naturally there is a value to having really salient structured sounds that are part of our natural environment actually have the brain develop normally so whether or not that has an impact you know while you're sleeping it's not clear I don't think that those studies have been done what was really clear was that the brain is not clear. So really clear was that if you raise these maybe rats and continuous white noise not super loud but just enough to mask the environmental sounds that that was enough to keep you know the auditory cortex the part of the brain that hears in this really delayed state which could essentially slow down the development and maturation of the brain. One probably assume that slowing the maturation of areas of the brain they're responsible for hearing might underscore might impact one's ability to speak right because isn't the case that if people can't hear they actually have a harder time in unseating in in a particular way is that right for you not be able to hear my own voice. Would my speech patterns change well I think part of it is that over time we develop sensitivity to the very specific speech sounds in a given language and. The sensitivity improves as we hear more and more and more of it and then I in the other hand we lose sensitivity to other speech sounds at the same time but it's part of that process we also have a selectivity again a specialization even. For those sounds even relative to noise noise backgrounds and things like that I tend to think about it like what is the signal to noise ratio and so the brain has its own ways of trying to increase that signal to noise ratio in order to make it more clear. Part of that is how we hear and how it lays down a foundation for that signal to noise ratio and so you can imagine a child that's that's raised continuously in white noise would be really deprived of those kind of sounds that are really necessary for to develop properly so I think with regard to those tools for babies I think we should study we should try to understand this definitively I think what we saw. And so we should be concerned about that but again it's not really clear if you're just using it night whether it has those effects. It's the critical question that a number of people are going to be asking is did you decide to use a white noise machine or not to help keep your any of your three children sleep. Well I think the short answer is no I mean I obviously did a lot of work thinking and work on this and thought about it carefully but there are other kinds of noise or I wouldn't even call a noise other sounds that you can use it can be equally soothing to a baby. It's just that white noise has no structure and what it's doing is essentially masking out all of the natural sounds and I think the goal should really be about how do we replace that with other more natural sounds that structure the brain in the way that we want to be more healthy. Well I know that after you finished your medical training you went on to or specialized in neurosurgery and last I checked you spend your most of your days either running your laboratory or in the clinic or running the department and your clinical work and your laboratory work involves often removing pieces of the skull of humans and going in and either removing things or stimulating neurons treating various ailments of different kinds. But your main focus these days of course is the neurobiology of speech and language and so for those that aren't familiar could you please distinguish for us speech versus language in terms of whether or not different brain areas control them and I know that there's a lot of interest in how speech and language and hearing all relate to one another. And then we'll talk a bit about for instance emotions and how facial expressions could play into this or hand gestures etc but for the un informed person and for me to be quite direct. What are the brain areas that control speech and language what what are they really and especially in humans how are they different I mean we have such sophisticated language compared to a number of other species what what is all this landscape look like in there. Yeah well that's a fascinating question and I'm going to just try to connect a couple of the dots here which is that in that earlier work during medical school I was doing a lot of what we call neuro physiology putting electrodes into the auditory cortex and understanding how the brain responds to sounds and that's how we actually mapped out these things about the sensitivity to sensitive periods. That experience with Mike Merznik and thinking about how plasticity is regulating and brain in particular about how sound is represented by brain activity was something that you know it was really formative for me and because I was a medical student I was going back to my medical studies. It was that in combination with seeing some awake brain surgeries that our department is really well known for one of my mentors Mitch burger really pioneered these methods for taking care of patients with brain tumor and be able to do these surgeries safely by keeping patients away can by mapping out language so they're talking and listening in your head essentially in conversation with these patients while there's a portion of their skull removed and you are stimulating or. In some cases removing areas of their brain is that right that's that's exactly right and the only thing off there is it's not essentially it's it is just that the only difference between the conversation that I might have with my patient who's undergoing a wake brain surgery is that I can't see their face and they can't see my face we actually have a sterile drape that actually separates the operating field and they're looking and interacting with our neuropsychologist but I can talk to them and I'm going to talk to you about the brain surgery. I can talk to them and they can hear my voice and vice versa and it's a really really important way of how we can protect some of those areas are really critical for language at the same time accomplished mission of getting the seizures under control or getting a brain to moment. And is that because occasionally you'll encounter a brain area maybe you're stimulating or considering removing that brain area and suddenly the the patient will start stuttering or will have a hard time formulating a sentence is that is that essentially what you're looking for you looking for. Regions in which it is okay or not okay to probe exactly so the first thing that we do is that we use a small electrical stimulator to probe different parts of the areas that we think might be related and are important for language or talking or even movements of your arm and leg that's what we call brain mapping and we use a small electrical current that's delivered through a probe that we can just put it each spot. And the areas that were really interested are of course the areas that are right around the part that is pathological the part that's injured or the part that has a brain tumor that we want to remove. And why that probe and transiently meaning temporarily activated so if you're stimulating the part of the brain that controls the hand the hand will move. It will jerk sometimes a fist will be made something like that other times while someone is counting or just saying the days of the week you can stimulate in a different area that stops their speech altogether that's what we call speech arrest. And someone is looking at pictures and they're describing the pictures and you're stimulating particular area they stop speaking or the words start coming out slurred or they can't remember the name of the object that they're seeing the picture. These are all things that we're listening really carefully while we apply that focal stimulation that's what we call brain mapping. What are some of the more surprising or maybe even if you want to offer one of the more outrageous examples of things that people have suddenly done or failed to be able to do as a consequence of this brain mapping. Well, I think the thing to me that has been the most striking is that you know some of these areas you stimulate and all together you can shut down someone's talking. So person says I wanted to say it but I couldn't get the words out and even though I've seen this thousands of times now it's still exciting every time that I see it because it's it's exciting because you're seeing the brain it's a physical organ it's part of the body outside of the veins on top of it doesn't look like. It's a machine but when you do something like that and you've fully changed the way it works and you see that because a person can't talk anymore and they say I know what I want to say but I couldn't get the words out. You're confronted with this idea that that organ is the basis of speech and language and way beyond that obviously you know for all the other functions that we have for thinking and and feeling our emotions everything. So that to me is a constant reminder of you know this really special thing that the brain does was compute so many of the things that we do in particular in the area around speech and language generating words something that is really unique to our species is just extraordinary to see again even though I've seen it thousands of times it's just having that connection because it doesn't look like machine but it is doing something that is quite complicated precise and remarkable. Do you ever see emotional responses from stimulation in particular areas and do you ever hear or see emotional responses that are associated with particular types of speech because for I would for instance curse words are known to people with to rats often will curse not always but it is sometimes they left texts or other things said. But what I learned from a colleague of ours is that curse words have a certain structure to them there's usually a heavy or kind of a sharp consonant up front right that allows people at least as it was described to me to have some sort of emotional release it's not a word like murmur which has a kind of a soft entry here I'm not using the technical language and pick your favorite curse word out there folks I'm not going to shout out any now or say any now but that certain words have a have a structure to them that because of the motor patterns that are involved in in saying that word yeah you could imagine has an emotional response unto itself so when stimulating or when blocking these different brain areas do you ever see people get angry or sad or happy or more relaxed. So well definitely I've seen cases where you can invoke anxiety stress and I think that there are also areas that you can stimulate you can also evoke the opposite of that sort of like a calm state. I think that brain areas is slightly hyperactive in you or at least more than than me and all the years I've known you you you've always been at least externally a very calm person I always find it amazing that you work on speech and language and you have a very calming voice right and I'm being really serious I think that there's a huge variation in that right in terms of how people speak in the how they accent words absolutely yeah so there are areas for example the orbital frontal cortex that we showed that if you stimulate there the orbital frontal cortex is a part of the brain that's above the eyes that's why they call it orbital frontal meaning it's above the eye or the orbit and in the frontal lobe and it's a very right in here it has really complex functions it's really important for learning and memory but one of the things that we observe is when you stimulate there people tended to have a reduction in their stress and it was very much related to their state of being that if someone was already kind of feeling normal and you stimulate there didn't do much but if someone was in a very anxious state it actually relieved that and then we've seen the corollary of that which is true too which is that there are other areas like the migdala or parts of the insula that if you stimulate you can cause an acute temporary anxiety a nervous feeling or if you stimulate insula people can have an acute feeling of disgust so you know the brain has different functions and these different nodes that help process the way we feel certainly I think that to some degree nurse psychiatric conditions reflect a name balance of the electrical activities in these areas one of the things that was something I will never forget was taking care of a young woman with uncontrolled seizures we call that epilepsy it's a medical condition where someone has uncontrolled electrical activity in the brain sometimes you can see that as convulsions where people are shaking and lose consciousness there are other kind of seizures that people can have where they don't lose consciousness but they can have experiences that just come out of nowhere and it's just as a result of electrical activity coming from the brain and about six years ago I took care of a young woman who was diagnosed psychiatrically with anxiety disorder for several years it turns out that it wasn't really an anxiety disorder was actually that she'd underlying seizures and epilepsy activating apart of a brain that evokes you know anxious feelings how did how was that discovered because I know a lot of people out there having anxiety I mean yeah in the absence of a brain scan how or why would one suspect that maybe they have a tumor or some other condition that was causing those neurons to become hyper happy yeah that's really important because so many people have anxiety and the vast vast majority are not having that because they're having seizures in the brain I think one of the ways that this was diagnosed was that the nature of when she was having these panic attacks was not triggered by anything they would just happen spontaneously and that's what can happen with seizures sometimes they just come out of nowhere we don't fully understand what can trigger them but they weren't things that were typically anxiety provoking this is something that just happened all of a sudden and because you brought it up this is not something that you can see on an MRI we could not see and look at the structure of her brain within MRI that she was having seizures the only way that we could actually prove this was actually having electrodes into her brain and proving that these attacks as she were having she was having were localized to a part called the meagdala it's a medial part of the temporal which is here and associating the electrical activity that we're seeing on those electrodes with the symptoms that she she had and she ultimately needed a kind of surgery where she was awake in order to remove this safely speaking of epilepsy a number of people out there have epilepsy or no people who do are the drugs for epilepsy satisfactory you know I think about things like depacote you know and adjusting the excitation and inhibition of the brain I mean are there good drugs for epilepsy we know there are not great drugs for a lot of other conditions but and how often does one need neurosurgery in order to treat epilepsy or can it be treated most often just using pharmacology yeah great question well a lot of people have seizures that can be completely controlled by their medications a lot but there's about a one third of people who have epilepsy which we define as anyone who's had three or more seizures that you know about a third of them actually don't have control with all of the modern medications that we have nowadays and some of the data suggests that if you have two or three medications it actually doesn't matter necessarily which of the anti seizure medications it is but there is data suggest if you've just tried two or three the fourth fifth six and beyond is not likely to help control it so we are in a situation unfortunately where a lot of the medications are great for some people but for another subset they can't control it and it comes from a particular part of the brain now fortunately in that subset there's another part of that bad group that can benefit from a surgery that actually either removes that part of the brain and nowadays we'll use stimulators now to sometimes put electrical stimulation in that part of the brain to help produce the seizures and you said a third of people with epilepsy might need neurosurgery well what I what I mean by that is like they continue to have seizures that are not controlled by all medications and there's going to be another subset of those that may benefit from a surgery it's probably not that whole third it's a subset of that it's just to say that epilepsy can be really hard to get fixed and for people where the seizures come from one spot or you know an area then surgery can do great if it coming from if it comes from multiple areas or if it comes from the whole brain then we have to think about other methods to control it fortunately nowadays there's actually other ways surgery now to us doesn't just mean we're moving part of the brain half of what we do now is use stimulators I modulate state of the brain that can help reduce the seizures I've heard before that the ketogenic diet was originally formulated in order to treat epilepsy in particular in kids is that true and why would being in a ketogenic state with low blood glucose reduce seizures that's a great question and to be honest I don't know actually if it was originally designed to treat seizures but I can't tell you for sure that for some people just like with some medications it can be a life changing thing can completely change the way that the brain works and it's not something that's for everybody but for some people there's no question it has some very beneficial effects I think it's to be determined still like why why and how that works I've heard similar things about the ketogenic diet for people with Alzheimer's dementia that there's nothing particularly relevant about ketosis to Alzheimer's per se but because Alzheimer's changes the way that neurons metabolize energy that shifting to an alternate fuel source can sometimes make people feel better and so a number of people are now trying it but it's not as if blood glucose and having carbohydrates is causing Alzheimer's and people get confused often that just because something can help doesn't mean that the opposite is harming somebody so I find this really interesting sometime I'll check back with you about what's happening in terms of ketogenic diets and epilepsy but you said that in some cases it can help as that observation been made both for children and for adults because I thought that originally the ketogenic diet for epilepsy was really for pediatric epilepsy yeah that's right so a lot of its focus has really been on kids with epilepsy but certainly it's a safe thing to try so a lot of adults you know we'll try it as well interesting I'd like to take a quick break and acknowledge one of our sponsors athletic greens athletic greens now called a G1 is a vitamin mineral probiotic drink that covers all of your foundational nutritional needs I've been taking athletic greens since 2012 so I'm delighted that they're sponsoring the podcast the reason I started taking athletic greens and the reason I still take athletic greens once or usually twice a day is that it gets to be the probiotics that I need for gut health our gut is very important it's populated by gut microbiota that communicate with the brain the immune system and basically all the biological systems of our body to strongly impact our immediate and long term health and those probiotics and athletic greens are optimal and vital for microbiotic health in addition athletic greens contains a number of adaptogens vitamins and minerals that make sure that all of my foundational nutritional needs are met and it tastes great if you'd like to try athletic greens you can go to athletic greens dot com slash huberman and they'll give you five free travel packs that make it really easy to mix up athletic greens while you're on the road in the car on the plane etc. and they'll give you a year supply of vitamin D3 K2 again that's athletic greens dot com slash huberman to get the five free travel packs and the year supply of vitamin D3 K2 I'm curious about epilepsy for another reason I was taught that epilepsy is an imbalance in the excitation and an inhibition in the brain and I think about these electrical storms that give people either grand mall you know shaking and kind of convulsions but years ago I was reading a book a wonderful book actually the Einstein in love by Dennis Overby it was about Einstein and his more I guess his personal life then people who knew him claim that he would sometimes walk along and then every once in a while would just stop and I can stare off into space for anywhere from a minute to three or five minutes and it was speculated that he had absence seizures what is an absence seizure and the reason I ask is I occasionally be walking along and I'll be thinking about something and I'll stop but I in my mind I think I'm thinking during that time but I realized that if I were to see myself from the outside it might appear that I was just absent what is an absence seizure because it's so strikingly different in its description from say a grand mall convulsive seizure sure well like I mentioned before depending on how the seizure activity spreads in the brain or how it actually propagates if it stays in one particular spot and doesn't spread to the entire brain it can have really different manifestation it can represent really differently so absent seizures just one category of different kind of seizures where you can lose consciousness basically what I mean by that is that you're not fully aware of what's going on in environment okay so you're sort of taking off line temporarily from consciousness but you could still be for example standing and to people who are not paying attention they may not even be aware that that's happening what are some other types of seizures well you know I think some of the other kinds are the classic ones are temporal lobe seizures so these are ones that come from the media structures like the magula and hippocampus oftentimes people when they have seizures coming from that they may taste something very unusual like a metallic taste or smell something like the smell of burning toast something like that there are some people will with temporal lobe seizures will have deja vu they will have that experience that you've been somewhere before but that's just a precursor to the seizure and it just highlights that when people have seizures coming from these areas these sometimes hijack what that part of the brain is really for so the magula and hippocampus for example are really important for learning and memory it's not surprising that when people have seizures there that it can invoke a feeling of deja vu or that it can invoke a feeling of anxiety and in the areas that are right next to it for example these areas are really important for processing smell so these areas are right next to each other so you can have these kind of complex set of symptoms the weird taste the smell of toast and then a feeling of deja vu that's classic for temporal lobe seizure and it's because those parts of the brain that process those functions are right next to each other I'm told that I've had nocturnal seizures and I've woken up sometimes from sleep having felt as if I was having a convulsion the sort of sense of buzzing in the back of the head it's happened to me two or three times in college my girlfriend well I woke up and my girlfriend was very distraught like you were having a seizure I was having a full convulsion in my sleep what are is that correct are there is there such a thing as nocturnal seizures what do they reflect they eventually stopped happening and I couldn't tether them to any kind of life event I wasn't doing any kind of combat sport or anything at the time I wasn't drinking alcohol much it's never really been my thing what are nocturnal seizures about oh well and do I need brain surgery nocturnal seizures are just another form like again epilepsy and seizures can have so many different forms and not just like where in the brain but also when they happen there are some people who for whatever reason it's very time to the circadian rhythm there's actually not just happening a night but a certain period a night when people are in a certain stage of sleep that the brain is in a state that it's vulnerable to having a seizure and so that's basically just one form of that again it's not just about where it's coming from but also when it's happening how that's timed with other things that are happening with the body interesting well it eventually stopped happening so I stopped worrying about it but I haven't had seizures since returning to speech and language when I was getting weaned in neuroscience I learned that we have an area of the brain for producing speech and we have an area of the brain for comprehending speech what's the story there is it still true that we have a broken and a vernicke's area those are names of neurologists presumably or neurosurgeons that discover these different brain areas and maybe you could familiarize us with some of the the textbook version of how speech and language are organized in the brain maybe share with us a little bit of the lesion studies that led to that understanding and I would love to hear a bit about what your laboratory is discovering about how things are actually organized because from some discussions you and I have had over the last year or so it seems like well let's just be blunt it seems that much of what we know from the textbooks could be wrong well I love that question because for me it's very central to the research we do and it's where the intersection between what we do in the laboratory and our research interfaces with what I see in patients and one of the things that fascinated me early on in my medical training was in doing some of these brain mapping or watching them with my mentor or taking care of patients and had brain tumors since during the part of the brain was that a lot of times what I was seeing in a patient did not correlate with what I was taught in medical school and you know some people will think well this might be an exception but after you see it for a couple of times and if you're kind of interested in this problem it poses a you know it poses a serious challenge to what you've learned and how you think about how these things operate and that actually got me really interested in trying to figure this out because earlier we talked about just this extraordinary thing that the brain is doing to create words and sentences and that's the process by which I'm getting ideas out from my mind into yours it's an incredible thing right it's the basis of communication high information communication between two individuals that's really unique to humans so in historical times how this works has been very controversial from day one of neuroscience long time ago people thought the bumps on your head corresponded to the different faculties of the mind so for example if you had a bump here might be corresponding to intelligence or another one over here you know to vision and these kind of things that's what we nowadays call phonology and that was kind of the starting point a lot of that has been of course debunked but when you see those little statues of different brain partitions on someone's head that's essentially what how people were thinking about how the brain worked back then a couple hundred years ago modern neuroscience began when actually was very much related to the discovery of language so modern neuroscience meaning moving beyond this idea that the bumps on the scalp corresponded to the faculties of the mind but there were things that actually were in the brain themselves and they weren't corresponding to things that you could see superficially like on the scalp or externally that it was something about the brain itself I mean it seems so obvious now but back then this was the big academic you know debate and the first observation that I think really was really impactful in the area of language was an observation by neurosurgeon French neurosurgeon named pure broca and what he observed was that in a patient not that he did surgery but that he had seen in taking care of the person couldn't talk and in particular they called this individual tan because the only words that he could produce was tan tan for the most part he could generally understand the kind of things that people were asking about but the only thing that he could utter from his mouth were these words tan tan and what eventually had happened was this individual passed away and the way that neuroscience was done back then was basically to wait until that happened and then to remove the brain and to see what part of the brain was affected in this patient that they call tan and what broca found was that there was a part in the left frontal lobe so the frontal lobe is this area like I described earlier which is up behind our forehead up here and in the back of that frontal lobe he claimed that this was the seat of articulation in the brain he literally used something like that in France the seat of articulation meaning that this is the part of the brain that is responsible for us to generate words about 50 years later the story becomes more complicated with a German neurologist named Carl Warnecke and what Warnecke described was a different set of symptoms in patients that he observed a different phenomenon where people could produce words but a lot of the word and they were fluent in the sense that they had like they sound like they could be real words but from a different language for example and some of us call that like word salad or jargon it's essentially they were essentially making up words but it was not intentional it was just the way that the words came out but in addition to that he observed that these people also could not understand what was being said to them so we could be having conversation and I'd be asking you am I a woman and you might nod your head because you're not processing the question you know and so here are two observations one is that the frontal lobe is important for articulating speech creating the words and expressing them fluently and then a different part of the brain called the left temporal lobe which is this area right above my ear that is an area that I think was claimed to be really important for understanding so the two major functions and language to speak and to understand were kind of pinned down to that and we've had that basic idea in the textbooks for you know over 200 years certainly what I was taught is that right? yeah certainly what we still teach undergraduate students and medical students that well that's what I learned to in medical school and what I saw in reality when I started taking care of patients was that it's not so simple in fact part of it is fundamentally wrong so just in a nutshell nowadays after you know looking at this very carefully over hundreds of patients we've shown that surgeries for example in the posterior part of the frontal lobe a lot of times people have no problem talking at all at all whatsoever after those kind of surgeries and that it's a different part of the brain what we call the precentral gyros the precentral gyros is a part of the brain that is intimately associated with the motor cortex the motor cortex is the part of the brain has a map of your entire body so it has a part that corresponds to your feet has a part that corresponds to your hands but then there's another part that comes out more laterally on the side of the brain that corresponds to your lips your jaw your larynx and we have seen that when patients have surgeries or injuries to that part of the brain it actually can really interrupt language so it's not as simple as just moving the muscles of the vocal track but it's also important for formulating and expressing words so that's a broken area that I think the field now recognizes not just because of our work but many other people that have studied this in stroke and beyond is that the idea that that is the basis of speaking in broken area is fundamentally wrong right now and we have to figure out how to correct the textbooks that we kind of understand that so that we can continue to make progress now in terms of the other major area that we call Warnakis area and the posterior temporal lobe that has helped I think quite legitimately for some time so that is an area that you have to be super careful when you do surgery there that's an area where if you have a mistake there and you cause a stroke or you move too much of the tumor there you go too far beyond it then the person can be really really hurt like they'll have a condition that we call aphasia where they may not be able to understand words they may not be able to remember the word that they're trying to say they know what they're trying to say but they can't remember the precise word that goes with the object that they're trying to think of they may even produce words that I described before are like word salad or very jargony so they might say something like Tamira and I that's not a real word but it sounds like it could be and that's just because that part of the brain has some role not just in understanding what we hear but also actually has a really important role in sending the commands to different parts of the brain to control what we say not long ago you and me and my good friend Rick Rubin were having a conversation about medicine and science and Rick asked the question what percentage of what you learned in graduate and or medical school do you think is correct and you had a very interesting answer would you share it with us? I don't know I don't remember the exact but I would say that with regard to the brain in particular I would say about 50% gets it right inaccurate and is helpful but another 50% is just the approximation and oversimplification of what's going on the example that we talked about language is just an example of that it's just there are things that make it easier to learn and easier to teach and easier to even think about and that's probably why we continue teaching in the way that we do but I think it's time goes on the complexity of reality of how the brain works is well first of all we're still trying to figure it out and second of all it is complex and it is it's still incomplete story it's early days and we get into some of the technical advances that are allowing some correction of the errors that the field has made and look no disrespect to the brain explorers that came before us and the ones that come after us will correct us that's the way the game has played but what I'm hearing is that there are certain truths that people accept and then there's about half of the information that is still open for debate and maybe even for complete revision one thing that I learned about language and the neural circuits underlying language is that it's heavily lateralized that these structures, brokers and vernickeys and other structures in the brain responsible for speech and comprehension of speech sit mainly on one side of the brain but they do not have a mirror representation or another or a equivalent area on the opposite side of the brain and for those that haven't poked around in a lot of brains certainly you any have done far more of that than I have but I've done my fair share in non-human species and a little bit in humans almost every structure, almost every structure has a matching structure on the other side of the brain so when we say the hippocampus we really mean two hippocampi one on each side of the brain but language I was taught is heavily lateralized that is that there's only one so that raises two questions one is that true and if it is true then what is the equivalent real estate on the opposite side of the brain doing if it's not doing the same function that the one on the left side is performing well that's one of those things that is again like mostly true not 100% and what I mean by that is that it's complicated so for people who are right handed 99% of the time the language part of the brain is on the left side and what is the equivalent brain area on the right side doing if it's not doing language? Well you know the thing that's incredible is if you look at the right side and you look at it very carefully either under an MRI or you actually look at the brain under slides at a microscope it looks very very similar it's not identical but it looks very very similar all the gyri which are the the bumps on the brain that you know have the different contours and the valleys that we call soul side all look basically the same like there is a mirror anatomy on the left and right side and so it's not been so clear what's so special actually about the left side to house language but what we do know this is what we use all the time in assessing and figuring out you know this before surgery is if you're right handed 99% of the time the language is going to be on the left side of the brain is handed in this genetic in any way I mean when I grew up a pen or pencil was or crayon was placed into my hand presumably or I started using my my father was left handed and then where he grew up in South America they they forced him to to force himself to become right handed actually used to restrict the movement of his left hand so he was forced to right so and then you have hook hook lefties and hook righties I know this is a deep dive and we probably don't want to go into every derivation of this but so for somebody who's left handed naturally just starts writing with the left hand there's some genetic predisposition to being left handed absolutely no question about it handedness is is not entirely but strongly genetic so there is something about the ties all of this and what does handedness for example have to do with where the part of your brain that controls language well it turns out that the parts that control the hand are very close to the areas that really are responsible for the vocal track again part of the motor cortex and part of this brain area called the precentral gyrus and there are some theories that because of their proximity that these parts of the brain might develop together early in utero and they might have a head start compares the right side and because they have a head start that things solidify there this is one theory of why this happens and people who are left handed it still turns out that the vast majority of people have language on the left side but it's not 99% it's more like 70% so if you're left handed it's still more likely that the language part of your brain is going to be on the left side but there's going to be a greater proportion maybe 20 30% where it's either in both hemispheres or on the right side and just to make this a little bit more interesting is that when people have strokes on the left side and if they're lucky enough to recover from those strokes sometimes that involves reorganization this term that we call plasticity earlier where the areas around where the stroke take on that new function a way that they didn't have before that can certainly happen in the left hemisphere but there are also instances where the right hemisphere can also start to take on the function of language where it was once on the left and then transfers to the right so the thing that I think about a lot is that the machinery probably exists on both sides but we don't use them together all the time in fact we may strongly bias one side or the other just like we use our two hands in very very different ways it's a little bit the same with the brain well it's because of what we do with the brain that actually is why we use the hands in different ways and the same thing goes for language which is that again the substrates the organ, the language organ, the part of the brain the process it probably has very similar machinery on the left side is the right and the right may have the capability to do it but in real everyday use the brain specializes one of the sides in order for us to use it functionally that's a theory you're bilingual correct? you speak English and Chinese for people that are bilingual and that learn two or more bilinguals obviously but learn both languages where let's say more languages from an early time in life do they use the same brain area to generate that language or perhaps they use the left side to speak English and the right side to speak Chinese do we know anything about bilingualism in the brain? I think we know a lot about bilingualism in the brain the answers are still out there the final answers on it and part of the answer is yes absolutely we use some parts of the brain very similarly we actually have a study in the lab right now where we're looking at this where people who speak one language or another or by the lingual and we're looking at how the brain activity patterns occur when they're here in one language versus the other and what's striking to see actually is how overlapping they really can be even though the person may have no idea of the language that they're hearing the English part of the brain is still processing that and maybe trying to interpret it through an English lens for example so the short answer is that with bilingualism there are shared circuitry there's the shared machinery and the brain that allows us to process both but it's not identical it's the same part of the brain but what it's doing with the signals can be very very different and what I mean by that precisely is not the instantaneous detecting of one sound to the next but the memory of the sequences of those particular sounds that give rise to things like words and meaning that can be highly variable from one individual to the next and those neurons are very very sensitive to the sequences of the sounds even though the sounds themselves might have some overlap between languages fascinating okay so we've talked about brain areas and a little bit about lateralization I want to get back to the hands and some things related to emotion and a little bit but maybe now we could go into those brain areas and start to ask the question what exactly is represented or mapped there and for people who perhaps aren't familiar with brain mapping and representation or receptive fields perhaps the simplest analogy might be the visual system where I look at your face I know you I recognize you and certainly there are brain areas that are responsible for face recognition but the fact that I know that that's your face and for those listening I'm looking at Eddie's face the fact that I know that that's your face at all is because we are well aware that there are cells that represent edges and that represent dark and light and we're all combined in what we call a hierarchical structure they sort of build up from basic elements as simple as little dots but then lines and things that move et cetera to give a coherent representation of the face when I think about language I think about words and just talking if I sit down to do a long podcast or I think about asking you a question I don't even think about the words I want to say very much I mean I have to think about them a little bit one would hope but I don't think about individual syllables unless I'm trying to you know it's something or it's a word that I have a particular difficulty saying where I want to change the cadence et cetera so what's represented in the neurons the nerve cells in these areas are they representing vowels, consonants and how do things like inflection like I occasionally will poke fun at upspeak but there's a I think a healthy normal version of upspeak where somebody's asking a question like for instance what is that that's an appropriate use of upspeak as opposed to saying something that is not a question and putting a lilt at the end of the sentence then we call that upspeak which doesn't fit with what the person is saying so what in the world is contained in these brain areas what is represented to me is perhaps one of the most interesting questions and I know this lands square in your wheelhouse Sure, let's get into this Andrew because this is one of the most exciting stuff that's happening right now is understanding how the brain processes these exact questions and you asked me earlier what is different between speech and language speech corresponds to the communication signal it corresponds to me moving my mouth and my vocal track to generate words and you're hearing these as an auditory signal language is something much broader so it refers to what you're extracting from the words that I'm saying we call that pragmatics and sort of getting the gist of what I'm saying there's another aspect of it that we call semantics do you understand the meaning of these words and the sentences there's another part that we call syntax which refers to how the words are assembled in a grammatical form so those are all really critical parts of language and speech is just one form of language there's many other forms like sign language reading those are all important modalities for reading our research really focuses on this area that we're calling speech again the production of this audio signal which you can't see but your microphones are picking up there are these vibrations in the air that are created by my vocal track that are picked up by the microphone in the case of this recording but also picked up by the sensors in your ear the very tiny vibrations in your ear are picking that up and translating that into electrical activity and what the ear does at the periphery is translates all sounds into different frequencies so it's main thing to do is to take a speech signal or any other kind of sound and decompose it meaning separate that sound into different kind of signals and in the case of hearing what it's doing is separating it out into low middle high frequencies it a very very high resolution it's doing it very quickly and it's doing in a really fine way to separate all of those different sounds so if you look at the periphery near the nerve that goes to your ear those nerve fibers some of them are tuned to low frequencies some of them are tuned to high frequencies some of them are tuned to the middle frequencies and that is what your ear is doing it's taking these words and splitting them up into different frequencies and for those of you out there that aren't familiar with thinking about things in the so-called frequency space bass tones would be lower frequencies and high pitched tones would be higher frequencies just to make sure everyone's on the same page so the sound of my voice, the sound of your voice or any sound in the environment is being broken down into these frequencies are they being broken down into very narrow channels of frequency or they want to avoid nomenclature here or they are they being bend as fairly broad frequencies because we know low medium and high but for instance I can detect whether or not something is approaching me or moving away from me depending on whether or not it sweeps or or right towards or away it's subtle but and of course it's combined with what I see in my own movement but how finely sliced is our perception of the auditory world? Oh extraordinarily precise I mean we take these millisecond cues the millisecond differences between the sound coming to one ear let's say you're right ear versus you're left to understand what direction that sound came from those are only millisecond differences and that's how precise this works but on the other hand it does a lot of computation on this it does a lot of analysis as you go up and a lot of our work is focused on the part of the brain that we call the cortex the cortex is the outer most part of the brain where we believe that sounds are actually converted into words and language so there's this transformation where at the ear words are decomposed and you know turned into these elemental frequency channels and then as it goes up through the auditory system hits the cortex there are some things that happen obviously before it gets to the cortex but when it gets to cortex there's something special going on which is that that part of the brain is looking for specific sounds and specifically what I mean by that is the sounds of human language so the ones that are the different consonants and vowels and a different language one of the ways that we have studied this is looking in patients who have epilepsy and in a lot of these cases where the MRI looks completely normal we have to put electrodes surgically on a part of the brain the temporal lobe is a very very common place so we've done a lot of our work looking at how the temporal lobe processes speech sounds because we're looking for where the seizures start but then we're also doing brain mapping for language and speech so we can protect those areas we want to identify the areas that we want to remove to cure someone's seizures but we also want to figure out the areas that are important for speech and language to protect those so that we can do a surgery that's effective and safe and so in our research and why it's become a really important addition to our knowledge is that we have electrodes directly recording from the human brain surface a lot of technology we work with right now is recording on the on the order of millimeters and they can order they can record millisecond time resolution of neural time resolution of neural activity and what we see is extraordinary patterns of activity when people hear words and sentences if you look at that part of the brain that we call warnikies area in this part of the temporal lobe this whole area lights up when you hear words or speech and it's not in a way that is like a general lipob warming up it's generally lit up but what you actually see is something much much more complicated which is a pattern of activity and what we've done in the last 10 years is try to understand what does that pattern come from and if we were to look at each individual site from that part of the brain what would we see? what parts of words are being coded by electrical activity in those parts of the brain? remember the cortex is using electrical activity to transmit information and do analysis and what we're doing is we're eavesdropping on this part of the brain as it's processing speech to try to understand what each individual site is doing and what are those sites doing or could you give us some examples of what those sites are doing? so for instance are they sites that are specific for or we could say even listening for consonants or for vowels or for inflection or for emotionality what's in there? okay well what makes these cells fire? yeah what gets them excited? what gets them going is hearing speech in particular there are some of these really focal sites again just on the order of a millimeter or at some level single neurons that are tuned to consonants, some are tuned to vowels are tuned to particular features of consonants what I mean by that are different categories of consonants there's a class of consonants that we call close of consonants there's a little bit of linguistics jargon but I'm going to make a point here with that is that certain classes of sounds when you make them it requires you to actually close your mouth temporarily now I'm going to be thinking about this so close of like close of like saying the word close of does that requires that exactly so what's cool about that is that we actually have no idea what's going on in our mouth when we speak we really have no idea some people definitely have no idea well not just like in terms of what you're saying sometimes but actually like how you're actually moving you know the different parts of vocal track and I have a feeling if we actually required understanding we would never be able to speak because it's so complex it's such a complex feat some people would say it's the most complex motor thing that we do as a species is is speaking not you know the extreme feats of acrobatics or athleticism and especially speaking you want especially when one observes opera or people who you know freestyle rappers you know and of course it's not just the lips it's the tongue and you've mentioned two other structures fairings and the main ones that the you tell us just just educate us at a superficial level what the fairings and larynx do differentially because I think most people aren't going to be familiar with it. So I'll talk primarily about the larynx here for a second which is that if you think about when we're speaking really what we're doing is we're shaping the breath so even before you get to the larynx you got to start with the exploration so we fill up our lungs and then we push the air out that's a normal part of breathing and what is really amazing about speech and language is that we evolved to take advantage of that normal physiologic thing out of larynx and what the larynx does is that when you're exhaling it brings the vocal folds together some people call them vocal cords they're not really cords they're really vocal folds they're two pieces of tissue that come together and a muscle brings them together and then what happens is when the air comes through the vocal folds when they're together they vibrate it really high frequencies like a hundred to 200 hertz yours is probably about a hundred hertz no no most male voices are on a hundred okay and then the average female voice around 200 hertz and as you know I've always had the same voice this is it was a shame when I was a kid folks my voice never changed I always had the same voice this is a discussion for another time well it's a great voice a great baritone voice but I know in your voice it's a low frequency voice and the reason why men and women generally have different voice qualities it has to do with the size of the larynx and the shape of it okay so in general men have a larger voice box or larynx and the vibrating frequency the resonance frequency of the vocal folds when the air comes through them is about a hundred hertz for men and about 200 for women so what happens is okay so you're taking you take a breath breath in and then as the air is coming out the vocal folds come together through that creates the sound of the voice that we call voicing and that's the energy of your voice it's not just your voice characteristic it's the energy of your voice it's coming from the larynx there it's a noise and then it's the source of the voice and then what happens is that energy that sound goes up through the parts of the vocal track like the pharynx into the oral cavity which is your mouth and your tongue and your lips and what those things are doing is that they're shaping the air in particular ways that create consonants and vowels so that's what I mean by shaping the breath it just starts with this exhalation you generate the voice in the larynx and then everything above the larynx moving around just like the way my mouth is doing right now to shape that air into particular patterns that you can hear is words fascinating and immediately makes me wonder about more primitive or non-learned vocalizations like crying or laughter babies will cry babies will show laughter and then there's a lot of vocalizations produced by the language areas like vernicies or do they have their own unique neural structures yeah interesting question so we call those vocalizations vocalization is basically where someone can create a sound like a cry or a moan that kind of sound of air it also involves some phonation at the level of larynx where the vocal folds come together to create that audible sound but it turns out that those are actually different areas so people who have injuries in the speech and language areas oftentimes can still moan they can still vocalize and it is a different part of the brain I would say an area that even non-human primates can be specialized for vocalization it's a different form of communication than words for example the intricacy of these circuits in the brain and their connections to the fairings and larynx is just it's almost overwhelming in terms of thinking about just how complicated it must be and yet some general features and principles are starting to emerge from your work and from the work of others if we think about that work and we think about for instance vernicke's area if I were to record from neurons in vernicke's area at different locations would I find that there's any and a systematic layout for instance in terms of we've talked about sound frequency we know that low frequencies are represented at one end of a structure and high frequencies at the other this is true actually at least from my earlier training within the within the year itself within the cochlea early work of phonbeckasy and from cadavers right they actually figure this out from dead people which is incredible a fascinating literature people should look up and in the visual system we know that for instance you know visual position where things are is map systematically in other words neurons that sit next to each other in the brain represent portions of visual space that are next to each other in the real world what is the organization of language in areas like vernicke's and brokas for instance um i think of the vowels a eiou uh as a kind of a coherent unit but do I find the a neurons or next to the e neurons or next to the uh or the the the a eiou is that val representation also laid out in order or is it kind of salt and pepper is it random that's been one of the like most important questions we've been trying to answer for the vast decade so uh there is a part of the brain that we call the primary auditory cortex and the primary auditory cortex is deep in the temporal lobe and if you looked at that part of the brain there is a map of different sound frequencies so if you look at the front of that primary auditory cortex you'll find low frequency sounds and then as you march backwards in that cortex it goes from low to medium to high frequencies it's organized in this really nice and orderly way and it turns out there's just not just one there's like mirrors of that um tone frequency map in the primary auditory cortex the areas that are really important for speech are on the side of that and we now think that speech can go straight to the speech cortex without having to go through the primary auditory cortex and it has its own pathway to get to the part of the brain the processes speech and when we've looked at that question about is there a map? the short answer is yes there is a map and it is um but it is not structured uh universally across all people in a way that we can clearly see right now it is like a salt and pepper map of the different features and speech so before we talked about these sounds that are called plosives you make a plosive when the mouth or something in the oral cavity closes temporarily and when it opens that creates that vast plosive sound so when you say um dad um or um you know the ball like the bee and ball that kind of thing you will notice that your your lips actually close and then it's the release of that that creates that particular sounds okay so those are the sounds that we call plosive those are like bada ga pata ka those are a certain class of constants and we call uh plosive sounds there's another class of sounds that we call fricatives and linguistics fricatives are created by turbulence in the the air stream as it comes out through the mouth and the in the the way that we make that turbulence is getting the mouth in the lips to close almost until they're completely shut or putting the tongue to near the teeth to almost get it completely shut but just have a narrow aperture that creates a turbulence in the air flow that we perceive as a high frequency sound so those sounds like shuh and thuh those kind of things those are if you look at the frequencies are higher frequencies and those are created by specific movements that you can strict the air flow to create turbulence and we hear it as shuh sa tha so if i say that exactly and as opposed to a plosive where i'd say explosive right i'm now of course i'm emphasizing here yeah well this explains and uh something in sols of mystery which is recently i've been fascinating by the work of a physician scientist um back yeast uh dr. Shane Aswan who's done a lot of work on um things that are contained in pesticides and foods that are changing hormone levels and she refers to thalates which is spelled so it's both a plosive and uh so it's combining the two and it's one of the most difficult words in the english language to pronounce um second only perhaps to the correct pronunciation of ophthalmology so it's a combination of a of a plosive and one of these thuh sounds and that's probably why it's difficult that's exactly right in fact um we have a term for that that's called a consonant cluster so sometimes syllables which have one consonant but when we start stacking certain syllables in a sequence and there's rules that actually govern which consonants can be in a particular sequence for a given language um that big that makes it more complicated and certain languages have a lot more consonant clusters than others so for instance so for instance russian for example has a lot of consonant clusters english has a lot of them the other languages that have very very few uh for example a hawayan hawayan has an inventory of about 12 to 14 different phonemes 14 different consonants and vowels english on contrast has about 40 uh different consonants and vowels so languages have different inventories they can overlap for sure but different languages use different sound elements combine and recombine those elements to give rise to different words and meanings can we say that there is a most complicated language out there or among the most complete would it be russian i'd definitely high up there english is up there too actually yeah german as well and in terms of learning multiple languages during development my understanding is that if one wants to become bilingual or trylingual best to learn those languages simultaneously during development ideally before age 12 if one hopes to not have an accent in speaking them later is that correct or do you want to revise that well basically the earlier and the earlier is better the more intensities and the more immersive it is uh the longer you know that you can be exposed to that is really important a lot of people can get exposed to early and basically lose it even though it's quote-unquote during that sensitive period unless it's maintained it can be very easily lost then i think another aspect of it that's very interesting is um some of the social requirements for it too it's pretty clear that you can only go so far um just listening to these sounds from a tape recording or something like that there's something extra about real human interactions that activates the brain sensitivity to different speech sounds allows us to become specialized for them for a given language so returning to the what's mapped what what the representations are in the brain i'm starting to get a picture now based on these plosives and these sounds uh and what i find so interesting and logical about that is it maps to the motor structures and the actual pronunciation of the sounds not necessarily to the meaning of the individual words now of course it's related to the meaning of the individual words but it makes good sense to me why something as complex as language both to understand and to generate would map to something that is essentially motor in design because as you point out i have to generate these sounds and i have to hear them generated from others however there's reading and there's writing and writing is certainly motor reading involves some motor commands of the eyes and etc where do reading and writing come into this picture are they in parallel with as we would say in neuroscience or are they embedded within the same structures are they part part of the same series of computations yeah so to address the first part is that we've got this map of these different parts of consonants and vowels and when we look at how they lay out in this this part of the brand that we call war in accuser area we spend a lot of time really just dissecting this millimeter by millimeter the term that you use is very apropos it's salt and pepper it's not random there is this kind of selectivity to these individual speech sounds and one point i want to make about it is this is that in english for example there are about 40 different phonemes phonemes or just consonants or vowels or individual speech segments but these articulatory features that you refer to for example the characteristic sounds that are generated by specific movements in the mouth you can more or less reduce that to about 12 different features okay these are specific movements of the tongue the jaw the lips the larynx there are about 12 of these movements and just like you said Andrew by themselves they have no meaning they're just movements but what's incredible about it is that you take these 12 movements and you put them in combinations and you start putting them in sequence we as humans use those 12 set of features to generate all words and because we can generate a nearly an infinite number of words with that code of just 12 features we have something that generates essentially all possible meaning because that's what we do as humans we generate meanings i'm trying to communicate one idea to another which to me is extraordinary a parallel would be for example DNA there's four base pairs and DNA but with those four base pairs in a specific sequence can generate an entire code for life and speech is the same way it's like you've got these fundamental elements that by themselves have no meaning but when you put them together give rise to every possible meaning so with regard to your second point about reading writing it's a fascinating question speech and language is part of who we are as humans that's part of how we evolved and it's hardwired and you know molded by experience reading and writing are human invention it's something that was added on to the architecture of the brain and because reading and writing are fairly recent in human evolution it's essentially too quick for anything to like have a dramatic change in let's say a new brain area or some kind of specialization instead what happens is that whenever any kind of behavior becomes ultra specialized in any of us or any organism we can sort of take some areas that are normally involved with vision for example and specialize it for the purpose of reading so all of us have a part of our brain in the back of the temporal lobe that interface with the sypital visual cortex that we call a visual word form area there's actually a part of the brain that is very sensitive to seeing words like either typed or handwritten there's a part of the brain that also sensitive to seeing things like faces so these are things that are all conditioned on what's important you know to survive so reading and writing are an invention and there are things that have mapped to functions that the brain already has and one of the really important things about reading writing is that when we learn to read and write especially with the reading part it maps to the part of the brain that we've been talking about which is the part that's processing speech sounds so some of us kind of think about it these are two different things one is hearing sounds three years the other is reading where you're actually seeing things through your eyes and then getting into languages so well it turns out that the auditory speech cortex is the primal and primitive fundamental area that's really important for speech and what happens with the reading is once it gets through that visual cortex it's going to try to map those reading signals to the part of the brain that's trying to make sense of sounds the sounds of words what we call phonology now wise is important it has a lot of relevance to how we learn to write and in some kids with dyslexia dyslexia is a neurological condition where a child in some cases an adult has trouble reading for example and in many of those cases it's because that mapping between how we see the words to the way that the brain processes the sounds is something different it's a little bit different than people who can read really well so when you're reading a lot of times you're actually activating the part of the brain that is processing the words that you hear what is the current treatment for dyslexia i've heard that it's a deficit in some of the motion processing systems of the visual system you know people are their eyes are jumping as opposed to more linear reading across or I suppose if we were Chinese who would be you know and to presume people are always reading English or I suppose if it's Hebrew they're going from the opposite side of the page what can be done for dyslexia and do any of the modern treatments for dyslexia involve changing changing things from the speech side as opposed to just the quote unquote reading side given that speech and reading are interconnected yeah absolutely so again I think in the beginning people might have thought this was purely a visual abstraction or something really just about the visual system but there's been more recognition that it could be both or it could be either depending on the particular instance it's very clear that there are many kids with dyslexia where the problem is a problem of a phonological awareness so you know it can be very hard to detect because they may understand the words that you were saying but because the brain is so good at pattern recognition sometimes even if the individual speech sounds are not crystal clear it can compensate that so that you can have an individual who can hear the words but not be able to essentially hear them when they're reading those same words and so what can happen with that is that you can have this disconnection between what they're seeing and what they need in order to hear it is words and process it is language and so skilled readers usually need that route first they've got a map the vision to the sound in order to get that sort of like foundation but then over time the reading has its direct connection to the language parts of the brain and we don't necessarily always need to map to sounds you know you can basically develop a parallel route and we as readers actually use both all the time so for example if it's a new word that you've never seen before sometimes you try to like pronounce it in your mind you know to try to hear what that word is even though you're not actually saying your trends just generate what those sounds might might be like and that's the part where we're kind of relying on how we learned to read in the first place which is mapping those word images to the sounds that you know go along with them but in other times if you're a really proficient reader you're just seeing the words and you can map them directly to meaning without having to go through that go through that process yeah I'm a big fan of listening to audio books and of course I also listen to podcasts quite a lot but I also a strong believer based on the research that I've seen that reading books physical books could be on kindle I suppose but reading a physical book is useful for being able to articulate well and structure sentences and build what are essentially paragraphs which is what I've required to do when I do solo episodes of the podcast I've noticed over the years as text messaging has become more popular and there's essentially an erosion of punctuation or the need to have complete sentences and now that sort of transferred to email as well it's become exact the bolt to just say you know fragmented sentences and email and it it seems likely that it's starting to impact the way that people speak as well and I don't think this does anything to do with intelligence or education level but are you aware of any evidence that how we read and what we read and whether or not we consume information purely through reading or mainly through auditory sources does it change the way that we speak because after all Vernecke's in Broca's area and the other auditory and speech production areas are heavily intermatched and so it would make perfect sense to me that what we hear and the patterns of sound they're being communicated to us would also change the way that we speak yeah that's a really fascinating point there's this idea that there's like this proper way to speak like that there's the right way for example what are the appropriate you know like for example in school you're oftentimes told like you should say like this not say like that you know and every language kind of has that it turns out that that's really unnatural languages and speech in particular change over time it evolves and it can it can happen very quickly you know the things that we call dialects for example are just different ways of speaking and someone can just be in one environment and change from one dialect to the other or in some people it kind of is really fixed and there's this idea that you know like in school that we're like told that there's this right way but in reality that's not true like language change and speech change is completely normal and happens all the time and it can be really dramatic like certain cultures and communities if they are isolated they can develop a whole new language a whole new set of of words for example new ways and dialects that are independent from people to the point where it's unintelligible even to to to others and so the basic idea is that sound change is hard of the way it works and the brain is very sensitive to those kind of changes. Speaking of learning new languages I'm assuming it's possible to learn new languages throughout the lifespan correct yeah I've also heard these kind of fantastical stories of somebody has a stroke and then suddenly spontaneously can speak French fluently whereas prior to the stroke they could not. Is there any merit to those stories whatsoever? I find it very hard to believe that there was a complete mapper of representation of a language in somebody's brain that they were completely unaware of and then because of damage to a brain area that capacity to speak that language was somehow unveiled. It just seems too wild and I don't want it to be true because nobody wants a stroke but it just seems outrageously implausible. Well there are aspects of that that certainly are implausible so I don't know of any true case that I've ever seen or experienced myself or even read about where for example there was an injury to the brain that resulted in loss of well essentially again a function meaning like this art of just all of a Sunset speaking another language so for example if you had a stroke and you never spoke French and then you had it and then all of a Sun you're speaking that I've never heard of never seen. However there is a condition that is well acknowledged and I have seen one case of this called a foreign accent syndrome which can is peculiar because there are people who have an injury to the part of the brain where it sounds like they're starting to speak this other language but they're not actually speaking the language it just sounds like it and this goes back to what we were talking about earlier about these areas that are really important for speech control of the the vocal track this area in the precentral gyres. People have documented where you know patients have had strokes there and after that it sounds like they're speaking Spanish as opposed to English or it sounds like they have the international properties of French or Russian as compared to their original native language. They're not learning all the recipe like the meaning and the grammar etc but they're adopting some of the phonology and part of that is just because it's not working the way it normally does so there is something actually called a foreign accent syndrome that people can have after a stroke. Interesting I'm curious about auditory memory when I was a kid I used to get into bed at night and I close my eyes and I would replay conversations that I had heard during the day or people's voices. I actually can remember calling your house when we were young kids and because I don't speak any Chinese but I'd have to ask for you I'd say I think it was Eddie Saibat-Sai. Yeah yeah yeah and then someone who ever answered the phone would say would go get you in the I say Shishir which I believe means thank you right that's the total of the Chinese that I speak by the way but I will never forget that. I'll just never forget it I hope I suppose if I have a stroke or something that's sort at some point I'll forget it and I won't know that I have forgotten it but in all seriousness I remember that to this day I couldn't spell that out I wouldn't know how certainly not in Chinese but even a transliteration I couldn't I couldn't do using English letters. Where are memories of sounds stored because within our days and across our lives we have an infinite number of auditory experiences just like we have an infinite number of visual experiences. Where are they stored and what is the structure of their storage? What am I calling upon? Besides of course the motor commands that are required to say what I just said in Chinese which I won't repeat again because I can somehow measure get right the first time or at least not terribly wrong then I don't want to botch it the second time. Where is that stored and how does that work and more importantly as I speak my native language English am I pulling from a memory bank because it doesn't feel like it. I'm just telling you what I want to say I'm doing my best to communicate clearly and succinctly usually not so good at the succinct part but where is the bank of information? On my keyboard on my computer I have the letters and I have certain elements of punctuation in the space. What am I pulling from? Am I pulling from those plosives? But if so how can I do it so quickly? Even for people that speak slowly it appears more or less fluid. This to me is overwhelmingly impressive that the brain can do that. How does it do that? Well first of all I'm impressed that 35 years later I had to get a hold of you. Yeah so I am impressed 35 years later that you can still remember that but only that. That's fine but I'm still very impressed and but it clearly is something important to you and so the short answer is that memory is very distributed so it's almost like the question that you asked me is ill-posed because you asked me where? Well it's not one specific area it's actually really distributed. It's not just one particular area. In fact I'm fairly certain that if we were to injure that part of the brain called the Warnakies area you may still even have memories of that. People can have injuries of Brokiss area or certainly the precentral gyros and be able to sing happy birthday for example when it's embedded in melody or highly rehearse things like counting despite not being able to speak which is incredible right? You can see a patient for example who can't really put together a sentence. You ask them how are you feeling today? They can't even get utter a word but then you ask them to count sometimes and they'll get up to any number really. There are some things that are really built into our motor memory and it's distributed. It's not one particular part of the brain. It's actually multiple areas where that memory is distributed. Thank God that's the way it is because it's very rare in the kind of surgeries that I do where you go and you remove a part of piece of the brain that someone forgets these kind of long-term memories or these long-term motor skills that they have. That's very very rare. It's the number one question the patient will ask me like, am I going to be the same and am I going to remember you know my wife or I mean I have I'm going to remember you know these thoughts of my birthday when I was 10 years old and I've never really seen that kind of severe. Unless it's a very very severe injury that involves almost the entire brain. Thank God. A lot of that information is really distributed across the entire brain. Speaking of storage of an ability to speak, you are doing some amazing work and have achieved some pretty incredible well-deserved recognition for your work in bringing language out of paralyzed people. Essentially allowing people who are locked in to a paralyzed state or otherwise unable to articulate speech using brain machine interface. Essentially translating the neural activity of areas of the brain that would produce speech into hardware, wires and things of that sort, artificial, non-biological tools in order to allow paralyzed people to communicate. We will provide a link to some of the popular press coverage of that work in the original papers but if you would be so kind as to tell us what those experiments look like, who these people are, who are locked in and that you allow to communicate. And then especially interesting to me are some of the directions that you're taking this now, which is beyond just people being able to think about what they want to say and words coming out on a screen or through a microphone but actually making the interactions between these people in the real world, more elaborate and more real. If that seems mysterious to people, I'm going to let Eddie tell you what they're doing with this rather than put any more detail on it. Okay, well thanks for asking about this. This has really been some of the exciting recent work from the lab. So for the last decade we've really been focusing on the basic science, meaning trying to understand how the brain extracts and produces speech sounds and words. We've done a lot of work trying to figure out how these parts of the brain control these individual elements that give rise to all words and meanings. And so it was about six years ago where we realized we actually have a pretty good idea of how this code works. We had identified all of these different elements that we could decode in epilepsy patients, for example, when they had electrodes on the brain as part of their surgeries. We could decode all of the different consonants in vowels of English. That was about six years ago. So a natural question was this, which is if we understand that electrical code, can we use that to help someone who is paralyzed and can't get those signals out of the brain to speak normally. And that's in the setting of people who are paralyzed. So there are a series of conditions. They include things like brainstem stroke. The brainstem is the part of the brain that connects the cerebrum, which is the top part, those are thinking and a lot of the motor control speech language, everything. And the brainstem is what connects that to the spinal cord and the nerves that go out to the face and vocal tracks. So if you have a stroke there, basically you could be thinking all the wild creative intelligent thoughts you have in the mind and the cerebrum, but you can't get them out into words or you can't get them out to your hand to write them down. So that's a very severe form of paralysis called brainstem stroke. There's another kind of conditions that we call neurogeogennerative where the nerve cells die basically or atrophy in a condition called ALS. And that's a very severe form of paralysis. And it's extreme form people essentially lose all voluntary movement. So Stephen Hawking would be a good example of someone with ALS, Lou Gehrig's disease. He's an example of someone who had ALS, but not a great example of what typical course of ALS. So for reasons not clear, the progression of his disease largely stabilizes at the point where he could twitch, you know, as a cheek muscle or move his eyes, let's say. And most people, it's very rapid and many people, they die from it actually, you know, within a couple years of diagnosis. So he lived a long time in that. He lived a long time in that. And slanted over state in this wheelchair. Exactly. But he wasn't breathing, you know, through a tube and his throat, for example, because people with severe ALS, the muscles to their to their diaphragm and their lungs essentially give out as well they get weakness there and then they can't breathe anymore. So that's another form of paralysis. And so in our field, these are kind of like the most devastating things that can happen. I'm not going to really try to compare like what's worse, you know, every brain tumor or stroke, it's all bad. But this condition of what we're called being locked in refers to this idea that you can have completely intact cognition and awareness, but have no way to express that. No voluntary movement, no ability to speak. And that is devastating because psychologically and socially, you know, you're completely isolated. That's what we call locked in syndrome. And it's devastating. I've seen that throughout my career and it's really heartbreaking because you know that the person is there, but you can't see, they can't communicate. So we've been studying this patterning of electrical activity for consonants and vowels. And essentially once we figured out a lot of these codes for the individual phonetic elements, we took a little bit of a detour or at least part of the lab started to focus on this very specific question. For people who have these kind of paralysis, could we intercept those signals from the brain, the cerebral cortex, as someone is trying to say those words? And then can we intercept them and then have them taken out of the brain through wires to a computer that are going to interpret those signals and translate them into words? So about three years ago, we started a clinical trial. It's called the Bravo trial. It's still underway. And the first participant in the Bravo trial was a man who had been paralyzed for 15 years. When he was about 20 years old, he came to the United States, was actually working in Sonoma area. And he was in a car accident and he actually walked out of the hospital day after that car accident. But the next day had a complication related to it where he had a very large stroke in the brainstem. And that turned out to be devastating. He didn't wake up from that stroke for about a week. He was in a coma for about a week. And when he woke up from that coma, he realized that he couldn't speak or move his arms or legs. And as he told me or communicated to us, that was absolutely devastating. He wanted really to die at that time. Could he blink his eyes or move his mouth in any way? He could blink his eyes. He had some limited mouth movements, but couldn't produce any intelligible speech. He was like completely slurred and incomprehensible. And he survived this injury. A lot of people who have that kind of stroke just don't survive. But he survived. And I also realized that he's just an incredible person like a force of nature in terms of his optimism, in terms of his ability to make friends despite his condition. The way he actually communicates, because he has a little bit of residual neck movements, is that he improvised and had his friends basically put a stick attached to his baseball cap. Because he could move his neck, he would essentially type out letters on a keyboard screen to get out words. In fact, this is how he communicated was through a device that he would essentially pack out letters one by one by moving his neck to control this stick attached to his baseball cap. How many years did he use that method of communication until about 15 years? He hadn't really spoken for about 15 years. Goodness. Yeah. So it was a devastating injury, but you know, there's something to be said about the human spirit. And if there's anyone who in the body said it is poncho, that's his nickname, the first participant in our trial. He has that human spirit. He persevered. In fact, you know, could thrive in his community basically and friends, be able to communicate in this very slow and inefficient way. Maybe part of that spirit is why he volunteered to be the first person in this trial. It was a clinical trial, an experiment. It was a study this is not an approved therapy by any means. This was really something that had not been done before. And was we had a lot of ideas about it, but we didn't know, you know, we had proven a lot of this could be true in some people who are normally speaking, but to actually put into someone who's paralyzed number one, where we don't know the code is the same. Number two is someone who's not been speaking for 15 years, whether those signals are actually still there or not. So it was part of a clinical trial. It was something that our hospital and also the FDA had to approve and looked at very carefully, but given a lot of the work that we had done, there were some bases for why this might work. And so about two and a half years ago, we did a surgery where we implanted electrodes onto the parts of the brain that we've been talking about, these areas that control the vocal track, the areas that control the larynx, the areas that control the lips and tongue and jaw movements when we normally speak. These are areas that presumably may be active. That was our hope in his brain, but he just couldn't get those out to control his mouth in a normal way. And he underwent a surgery, a brain surgery, we put an electrode array, and we connected it to a port that was screwed to his skull. And the port actually goes through his scalp, and he's lived with this now for the last three years. It is a risk of infection. These ports eventually have to become wireless in the future, but we figured out a way to keep that port there where we can essentially connect him to a computer through that port. So he has an electrode array that's implanted over the part of this brain that's important for speech. It's connected to a port. And then we connect a wire to that port that translates those what we call analog brainwaves and converts them into digital signals. And then a computer takes those digital signals from those individual sites from the speech cortex and translates those into words. Can you describe for us the first time that Poncho spoke through this engineered device? What was that experience like for you? And at least from what he conveyed to you, what was that experience like for him? Is this somebody who was essentially locked in, except for this rather crude pecking device? Although I'm thoroughly impressed by how adaptive where adaptable Poncho was in his friends engineering that device form was really nothing short of clever. And because otherwise he would be truly locked in. But what was that moment like? I can only imagine. That moment was incredible. It was truly incredible to be able to see him try to get out of word that was for all practical purposes unintelligible. But to be able to take the brain activity and to translate it into text on a screen. That's what we did. We took those brainwaves. We put them through machine learning or artificial intelligence algorithm that can pick up these very, very subtle patterns. You can't actually see them with your eye in the brain activity and translate those into words. And I remember seeing this happening for the first time, you know, it doesn't happen like immediately. This is something that took weeks to train the algorithm to interpret it correctly. But what was incredible about it was to see how he reacted. And he would be prompted to say a given word like, you know, outside, for example. And then you would think about it, try to say it. And finally, those words would appear on the screen. And what was really amazing about it was you could really tell that he like got a kick out of that because he would start to giggle. You know, his his body would shake in a way and his head would shake in a way that he would start to giggle. And that was cool to see. But then I also realized that when he was giggling, it kind of screwed up the next words decoding. Is that a bug you've since fixed? No, we haven't fixed that. Interesting. We haven't fixed that. So it's easier just to tell him to stop giggling. So what was the first word that he said? Well, I think one of the first sentences that he put together was, you know, can you get my family outside? And you didn't get them out of the room? No, no. All these years, you wanted to go through his family. No, I think what he meant was, can you get them in? Bring them in. Bring them in. And so the way this worked was we trained this computer to recognize 50 words. We started with a very small vocabulary. That's expanding as we speak. I think that this is just a matter of time before these vocabularies become much, much larger. But we started with a 50 set of words. We created essentially all the possible sentences that you could generate from those 50 words. Why that was important was you can use all those possible sentences to create a computational model, a computer model, all the different word combinations to give different sentences, given those 50 words. And then you can essentially do what we call auto correct. It's the same kind of thing that we do when you're texting, for example, you get the right, the wrong letter in there, but your phone actually knows because it's context, what corrected. So because the decoding is not 100% correct all the time, in fact, as far from that, it's really helpful to have these other features like auto correct, the stuff that we use routinely now with texting that makes it correct and then updates it. So it's a combination of a lot of things. It's the AI that is translating those brain activity patterns, but it's also things that we've learned from speech and speech technologies that you know you put all together and then all of a sudden it starts to work. And so we were really excited because that was the first time that someone was paralyzed and could create words and sentences that was just decoded from the brain activity. Incredible. And I know you're very humble, but I'm going to embarrass you by saying I always knew you were destined for great things since the early age of nine when we first became friends, but when I read that the news coverage of your work with Poncho and the release of this language from this locked inpatient, it literally brought tears to my eyes because it's an interesting thing as fellow neuroscientists, right? We explore the brain and we try and find mechanisms and we try and compare those to what other people find and find truths and principles and build up from those. But pretty rarely is there a case where that route of exploration leads to something of clinical significance within one's own lifetime. I mean that's the reality of science and oftentimes it's a very distributed process. But in this case, it's been a it's been a magnificent thing to see you move along this trajectory, parsing these languages, speech areas, and then to also do the clinical work in parallel. Speaking of which, these days we hear a lot about neural link, Elon Musk's company, a neurosurgeon that came up briefly through my lab, but I can't take any credit for what he knows or does, which is Matt McDougal is the neurosurgeon at neural link. There's some other excellent neuroscientists there and engineers there. We hear a lot about neural link because while brain machine interface of the sort that you do and that other laboratories do, has been going on for a long time, there's been some press around neural link about the promise of what brain machine interface could do. For instance, early in our discussion you talked about how you know, language is constrained by these sound waves and typically it's a few people communicating or one person with many people through a podcast, for instance, or a speech. But the idea has been thrown out there that through the use of stimulating chips or through other brain machine, devising that perhaps one could internalize 50 conversations in parallel, 50X communication or that the memory systems could be augmented to remember 10 times as much information or even twice as much information in a given period of time. My understanding of what they're doing at neural link, which is admittedly crude and from the outside, a few discussions with people there, is that they too are going to pursue clinical goals first. Things like trying to generate smooth movement in a Parkinsonian patient, trying to adjust movement patterns in someone with Huntington's disease, for instance, things of that sort before they embark on the more sci-fi like explorations of 50Xing communication or doubling memory capacity in these kinds of things. Although, I don't know, they may be doing all of those things in parallel. What are your thoughts about super capabilities of the brain? I don't even know what word to use. Supercharging the brain, giving the brain functions for which we've never observed before in human history. But we have our Einstein's and our Feynman's and our Merzenix and the unclear who to put in along that line, aside by side. But there are some Michael Jordan's and etc. But we've never heard of or seen somebody who can jump 20 feet in the air. Or we've heard of people who have photographic memories. But I don't know that we are aware of any human being in history who could memorize the entire library of Congress or all the works within the Vatican within an hour. Anyway, you get the idea. What are your thoughts about manipulating neural circuitry to achieve superhuman or superhuman or super physiological functions? Are we there? Should we even be thinking about that? Is it possible, given that neurons simply communicate through electrical activity and electrical activity can be engineered outside of the brain? How do you think about it? And here, we don't even have to think about neural link in particular. It's just about one example of companies and people and laboratories that are quite understandably considering all this. Well, it's a really interesting time right now. The science has been going on for decades. The work that we've done in this field that you call brain machine interface has been going on for a while. And a lot of the early work was just trying to restore things like our movement or having people or monkeys control a computer cursor, for example, on the screen. That's been going on for decades. What's been really new is that industry is now involved and some of this is now becoming commercialized. And we're starting to see a snout crossover to this field where it's no longer just research that we're talking about medical products that are designed to be surgically implanted. In some cases, there's people doing this kind of work non-invasively as well. They don't require surgery. The specific question that you're asking about is an area that we call augmentation. So can you build a device that essentially enhances someone's ability beyond supernormal, supermemory, super communication speeds beyond speech, for example? I guess superior precision, athletic abilities. I think that these are very serious kind of questions to be asking now because as you mentioned, the pathway so far is really to focus on these medical applications. I personally don't think that we've thought enough actually about what these kind of scenarios are going to look like. And I don't think we've thought through all the ethical implications of what this means for augmentation in particular. There's part of this that is not new at all. Humans throughout history have been doing things to augment our function. Coffee, nicotine, all kinds of things, all kinds of medications that cross over from medical to consumer. That is everywhere. So the pursuit of augmentation or performance or enhancement is really not a new thing. The questions really, as they relate to neuro technologies, for example, have to do with the invasive nature. For example, if these technologies require surgery, for example, to do something that is not for a medical application. Again, there that is not exactly a new territory either. People do that routinely for cosmetic kind of procedures for physical appearance, not necessarily cognitive. So I do think that provided the technology continues to emerge the way that it does, that it's going to be around the corner. And it probably is not going to be in ways that are super obvious. I don't think it's going to be like, can we easily memorize every fact in the world? But in forms that are going to be much more incremental and maybe more subtle. In many ways, we already have that now. For example, you don't have to have a neural interface embedded in your brain to get information, essentially access to all information in the world. You just have to have your iPhone. Whether you could do it faster through a brain interface, I definitely wouldn't rule that out. But think about this. That the systems that we have already to speak and to communicate have evolved over thousands and millions of years. And they're supported by neural structures that have bandwidth of millions of neurons. There's no technology that exists right now that people are thinking about that are in commercial forms, certainly, not even in research labs that come anywhere close to what has been evolved for those natural purposes. So I'm essentially saying two sides of this, which is we're already getting into this now. This is not new territory, this topic of augmentation, both physical and cognitive. We've already surpassed that. That's part of what humans do in general. But we are entering this area of like enhanced cognition. These areas that I think the technology is going to be the rate limiting step and how far we can go. We have not had the full conversations about number one, is this what we actually want? Is this going to be good for society? Who gets access to this technology? These are all things that are going to become real world problems. Certainly a lot to consider. In thinking about augmentation and another theme that yet to ask you about, but I'm extremely curious about which is facial expressions. Before we talk about the relationship between the musculature of the face and language and the communication of emotion, I'd love for you to, if you would, touch on a little bit of what you're doing with patients like poncho to move beyond somebody who's locked in being able to type out words on a screen with their thoughts. There's a rich array of information contained within the face and facial expression. And while somebody like poncho going from having to be completely locked in to being able to peck out letters on a keyboard to being able to just think of those letters and having them spelled out, that's a tremendous set of leaps forward towards normalcy. It's still far and away different than poncho speaking with his mouth, which I think knowing some people who are restricted who are quadriplegic, a lot of what they struggle with in the reward is actually actually a height difference sometimes because they're seated while other people are standing. This actually, we don't often think about this, but always have to look up to communicate with people's a very different interface in the world. They manage quite well, of course, but could you tell us what you're doing in terms of merging the brain machine interface with extraction of speech signals from people who are locked in like poncho with facial expressions? Sure, yeah. Well, like we described before progress is being made, the proof of principle is out there that you can decode speech. That will continue to optimize, and I'm very confident that that's going to improve very, very quickly in the coming years to the point where it's like, you know, not just a small vocabulary, but a large vocabulary and a reasonable rates. At a level that's going to be really helpful. I'm very optimistic about that. I think it's the right time to start really thinking about a broader vision of what communication really is. So, for example, I'm here with you in person. We could have done this virtually, probably. It's pretty easy to do that. We could have recorded this really separate, but there is something about being able to actually see your expressions and to understand other forms of communication. So, another really important one is nonverbal. The expressions that you're making, you know, for example, if you have a physical look on your face, if I'm saying something not clear, that's assigned to me that I need to rephrase it, or to say it in a different way, or slow down, for example. Or if there's something that really excites you, I want to continue to say more about it and talk more in detail, you know, essentially about a given thing. So, facial expressions actually are a really important part of the way we speak. And there's two things. It's not just the expressions of how you're feeling and perceiving what I'm saying, but it's also seeing my mouth move. In your eyes, I actually see my mouth move, and my jaw move in a particular way, that actually allows you to hear those sounds better. So, having both the visual information, but also the sounds go into your brain, is going to improve the intelligence brilliantly, also make it more natural. And memory for what is spoken? Perhaps. So, here's a call for people not just listening to podcasts, but watching them and listening to them on YouTube, I suppose, if we were to translate this to... Exactly....the real world. Exactly. And the reason why we're also very interested in this idea of not just having text on a screen, but essentially a fully computer animated face, like an avatar of the person's speech movements, and their visual expressions, is going to be a more complete form of expression. Now, you can imagine right now that might just be someone looking at a computer screen interpreting these signals, but I think the way things are going in the next couple of years, a lot more of our social interactions, more than even now, are going to move into this digital virtual space. And of course, most people are thinking about what that means for most consumers, but it also has really important implications for people who are disabled, right? And whether how are they going to participate in that? And so, we're thinking really about for people like Podge and other people who are paralyzed, what other forms of BCI can we do in order to help improve their ability to communicate? So, one is essentially building out more holistic avatars, things that can essentially decode, essentially their expressions, or the movements associated with their mouth and jaw when they actually speak to improve that communication. So, do you envision a time not too long from now where instead of tweeting out something in text, my avatar will, I'll type it out, but my avatar will just say it. It'll be an image of my avatar saying whatever it is I happen to be tweeting at that moment. That's what we're working on. Yeah, so I don't think that that is going to happen and it's going to happen soon. And there's a lot of progress in that. And again, we're just trying to enrich the field of communication, expression, to make it more normal. And we actually think that having that kind of avatar is a way of getting feedback to people learning how to speak through a speech neuroprosthetic. That's the device that we call it, speech neuroprosthetic. That is going to be the way that can help people learn how to do it the quickest, not necessarily like trying to say words and having it come on a screen. But actually, it have people embody, feel like it's part of themselves or that they are directly controlling that illustration or animation. So this idea of an avatar speaking out what we would otherwise write is fascinating to me on Instagram. I post videos. I don't filter them. But I know there's a lot of discussion nowadays about people using filters to make their skin look different or the lighting look different, a lot of filtering and also the use of captions. So that essentially what you end up with is somewhere between an actual raw video of what was spoken and an avatar version of it. I mean, if the mismatch between what's spoken and what's in the caption is too dramatic, then it doesn't quite work. But I watch these carefully when people use captions. And oftentimes there's a smoothing of what was said into the caption. So it seems much more succinct and accurate. Oftentimes the reverse is also true where the caption is inaccurate. And then it creates this kind of jarring mismatch. In any case, I think this this aspect in the clinical realm of using an avatar to allow people like poncho to essentially be a face that communicates through spoken language from an avatar that looks like them is fascinating and indeed important. And I think how avatars emerge in social spaces is going to be really fascinating. I get a lot of questions about stutter. I think that for people who have a stutter, it is itself anxiety provoking. Is stutter related to anxiety? If one has a stutter, what can they do? The stutter reflect some underlying neurologic phenomenon that might distinguish between one kind of stutter and another. What can people with stutter do if they'd like to relieve their stutter? Yeah, great question. Stutter is a condition where the words can't come out fluently. So you have all the ideas you've got the language. In fact, remember we talked about this distinction between language and speech. Stuttering is a problem of speech. So the ideas, the meanings, the grammar, it's all there and people stutter, but they can't get the words out fluently. So that's a speech condition. And in particular, it's a condition that affects articulation, specifically about controlling the production of words in this really coordinated kind of movements that have to happen in the vocal track to produce fluent speech. And stuttering is a condition where people have a predisposition to it. So there's an aspect of stuttering. You are a stutterer or you're not a stutterer, right? But people who stutter don't stutter all the time either. So you could be a stutter who stutters at some times, but not others. And really the main link between stuttering anxiety is that anxiety can provoke it and make it worse. That's certainly true. But it's not necessarily caused by anxiety. It can essentially trigger it or make it worse, but it's not the cause of it per se. So the cause of it is still really not clear, but it does have to do with these kind of brain functions that we've been talking about earlier, which is that in order to produce normal fluent speech, we're not even conscious of what is going on in our mouths and our larynx. We're not conscious. And if we were, we'd not be able to speak because it's too complex, it's too precise. It's something that we have really developed the abilities to do and we do it naturally, right? It's part of our programming and part of what we learn inherently and it's just through exposure. So stuttering is essentially a breakdown at certain times in that machinery being able to work in a really coordinated way. You can think about the operations of these areas that are controlling the vocal tract. Let's say speeches like a symphony in order for it to come out normally. You've got to have not just one part, the larynx, the lips, the jaw. They can't be doing their own thing. They have to be very, very precisely activated and very, very precisely controlled in a way to actually create words. And so in stuttering, there's a breakdown of that coordination. If somebody has a stutter, is it better to address that early in life when they're still neuroplasticity is very robust? And so what's the typical route for treatment? I have to imagine it's not brain surgery typically. I'm guessing there are speech therapists that people can talk to and they can help them work out where they're getting stuck in the relationship to anxiety. Yeah, exactly. I mean, part of it is about that anxiety, but a lot of it really has to do with therapy to sort of like work through and think of tricks basically sometimes to create conditions where you can actually get the words to come out. A lot of some forms of stuttering are really initiation problems. Just getting started itself is very hard. You want to start with initial bowel or consonant, but it won't emit. And so a lot of the therapy is really just focusing on how do you create the conditions for that to happen. There's another aspect to it that I find very interesting is that the feedback essentially what we hear ourselves say, for example, in every time that I say a word, I'm also hearing what I'm saying. So that's what we call auditory feedback. That turns out to be very important. And sometimes when you change that, you can actually change the amount someone's stutters for better or for worse. And it's giving us a clue that the brain is not just focused on sending the commands out, but it's also possibly interacting with a part that is hearing the sounds. And there's something might be going on in that connection that breaks down when stuttering occurs. So there are individuals that are stutters, but they don't stutter all the time. In those instances, there's something happening in those particular moments where this very, very precise coordination needs to happen in the brain in order to get the words out fluently. We talked a little bit about caffeine and why you avoid it. Because your work requires such precision and calm and frankly, to me, it seems like you're running a lot of operations and no pun intended in parallel when you're doing surgery, not just thinking about where to direct the instruments, but also thinking like a chess player, several steps down the line, what could happen, what if then type thinking? Some of the other practices and tools that you use to put yourself into state for optimal neurosurgery or for thinking about scientific problems for that matter. We keep threatening to go running together, but I know you run. Correct? Yeah. Do you find running to be an essential part of your state regulation? Absolutely. Yeah. So for me, most exercise that I do, I really don't do for physical reasons. I do it for mental reasons. I can tell, for example, if I don't go on a run or a swim just after a day or two, and it can have translation, for example, and the way I feel in operating room or even the way I interact with other people. So there's no question that those, you know, the mind and body are deeply connected. And for me personally, be able to have opportunity to disconnect for a while. It turns out to be really, really important. Now, the operating room for me is another space, kind of like running or swimming, where I'm disconnected from the rest of the world. I don't bring my cell phone into the operating room. I'm disconnected from the external world for that time that I'm in the surgery. And all I am doing is just focusing. Now, that doesn't mean that I'm having complex thoughts or doing something very complicated. Sometimes it is like that, but it's not always like that. There are things that we do in surgery that are like routine and wrote and are from muscle memory. So for example, suturing skin or doing certain kinds of dissection or drilling part of the bone, for example, these are all things that become very rote after a time. So for me, even being in the operating room, actually can sometimes fulfill that purpose. So I really look forward to being in the operating room because that intense focus allows me to disconnect from all the other things that I'm worrying about, you know, that are happening on the outside world. You know, we all have those kind of things that happen. And I'm certainly no exception to that. But strangely, the operating room for me is a sanctuary. I love being there because we have some control over the environment. I know what is there. I know the anatomy of the brain. My motions are going through routines. And so for me, that's not actually very different than going on a run and letting my, you know, likes moving specific ways. It's just the same thing for my hands. Do you listen to music or audiobooks when you run? Are you divorced from technology when you run? Well, music helps me like just stay motivated and distracted from being out of breath and other things. And for me, it's a way to just to catch up with like the world. So sometimes I do, but I do notice that like I don't run as well, for example. In the operating room, it's a little different, you know, different surgeons have preferences. I'm more of the camp where I don't like any distraction whatsoever. I like people to be able to hear the words that I'm saying without having background noise. I don't really think about relying on music or other things to try to put me in a state of mind, you know, I think just being there alone and just, you know, trying to try to treat it the way it is. It's a sacred moment where someone's life is really directly under your hands. That enough kind of focuses me very quickly. And I like that. It really detaches me from a lot of things that are preoccupying me. And for those couple of hours that we have a surgery, we're just focused on one thing only. It's fantastic. Again, I think of in the range of brain explorers, the neurosurgeons, those of your profession are to me like the astronauts of neuroscience because they're really going to the farthest reaches possible and they're testing and probing and really at the front edge of discovering from the species that we arguably care about the most, which is humans. Eddie, I have to say, from the first time we became friends 38 years ago, something like that. I'm almost reluctant to say what, so I only reveal it in part that Eddie and I became friends because both he and I shared a love of birds and we had a club at our school of which there were only two members. Eddie and I. Small club. Small club. There was one honorary member and there were certain requirements for being in this club that we won't reveal. We took a packed of secrecy and we're going to obey that packed of secrecy. To be sitting here with you today for me is an absolute thrill. Not just because we've been friends for that longer that we got reacquainted through literally the halls of medicine and science, but because I really do see what you're doing as really representing that front absolute cutting edge of exploration and application. The story of poncho is about one of your many patients that has drive tremendous benefit from your work and now as a chair of a department, you of course work alongside individuals who are also doing incredible work in the spinal cord, etc. So on behalf of myself and everyone listening, I just really want to thank you for joining us today to share this information. We will certainly have you back because there's an entire list of other questions we didn't have time to get to, but also just for the work you do. It's truly spectacular. Andrew, thanks so much. I'm very humbled, basically, by what you just said. I feel that it's really an extraordinary honor actually and privileged to be here with you and reconnect and talk about all these ideas. It's probably not random that we ended up in similar spots and interests. I think when we were kids, it starts with some deep interests and and kind of nerding out on topics and it's probably not a coincidence that we have such deep interests in this work. Now, I just feel really lucky to be able to do what I do. It's fun every day, almost every day. Be able to go to work and take care of folks and learn at the same time and then just close the loop. How do we apply the knowledge that we learn one day to someone who comes in next week? It's really fun and we don't know everything. We're not even close to it, but the journey to figure this out is it's really extraordinary. It's like you said, it's exploring new lands literally in the operating room when I'm looking at the exposed cortex. Trying to understand is it safe to walk down this part of the cortical landscape or this other trail? Which one is going to be the one that is going to be safe versus the other that results in paralysis and inability to talk? Well, maybe I shouldn't call it fun, but it's very important too in addition to being really intellectually important for how we understand how the brain works. And so yeah, I feel just really lucky to be in that opportunity. I'm really lucky to have you being one of the people doing it. So thank you ever so much. Thanks. Thank you for joining me today for my discussion with Dr. Eddie Chang. If you'd like to learn more about his research into the neuroscience of speech and language and bioengineering, his treatment of epilepsy and other aspects and diseases and disorders of the brain, please check out the links in our show note captions. We have links to his laboratory website, his clinical website and other resources related to his critical research as well. If you're learning from and are enjoying the Hubertman Lab podcast, please subscribe to our YouTube channel. That's a terrific zero cost way to support us. In addition, please subscribe to the Hubertman Lab podcast on Spotify and Apple. And on both Spotify and Apple, you also have the opportunity to leave us up to a five star review. If you have questions for us or comments about the information we've covered or suggestions about future guests, please put those in the comment section on YouTube. We do read all the comments. Please also check out the sponsors mentioned at the beginning of today's episode. 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And as always, thank you for your interest in science.