My Serendipitous Path to Cochlear Implants

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Early Dream Realized

Growing up in Kolkata (see bit.ly/4dnEnmW), a big, busy, vibrant city in India, I had occasional opportunities to volunteer at a residential institution for children with major neurological and other challenges that often were due to poverty and related causes. Years later, as an undergraduate student in electrical engineering at Jadavpur University, Kolkata (see bit.ly/4dF7xNV), I would reflect on those children and wonder what could be done to help. What could have gone so wrong with their neural systems to affect mobility, cognition, and communication?

These thoughts turned into questions about the brain and neural systems. I found myself reading anything I could get my hands on that discussed the brain, neurons, and neural networks. I hadn't heard the word "neuroscience" as yet, but I was really making up the field in my head. With all the ignorance and confidence of youth, I decided that I would figure out how neurons worked and then come up with a prosthesis that would help people with neurological problems.

Not finding relevant programs in my country, I visited the United States Educational Foundation of India (which fortunately had an office in my city; see usief.org.in/Kolkata.aspx) in my senior year and asked if they had any programs to suggest for an engineer trying to learn about neurons. Needless to say, they had no idea what I was talking about, and I had to find a creative way to get into their "library," a room full of guides to various graduate programs in the United States.

After spending a couple of fruitless days looking through endless programs (neuroscience was mostly for biology majors in the late 1980s and a nascent field even in the United States), a truly serendipitous event happened. A slim white brochure fell out from in between two volumes of college guidebooks and into my hands. It advertised a PhD in neuroscience designed for engineers, physicists, or mathematicians! This was the program that Jozef (Joe) Zwislocki (see bit.ly/3SIxdBl) had founded at the Institute for Sensory Research at Syracuse University, Syracuse, New York. The brochure had a picture of a neuron, with the membrane charging equation (which I identified easily from my engineering coursework). I immediately went about finding out how to apply, took the Graduate Record Examination and the Test of English as a Foreign Language, and somehow got an application submitted for the fall of 1987.

I was admitted to the Institute but having applied too late for financial aid, it all fell through for lack of funding. There was no way my professor parents could afford to pay for tuition and living expenses in the United States (professors were paid very little in India in those days). I hadn't really thought I would get in, the distance between Syracuse and my neighborhood in India seemed simply too vast, but I had been (irrationally perhaps) hoping that it would work out; the negative outcome was depressing.

I started looking into other graduate programs in India and contemplated applying for jobs as an electrical engineer. A few months later, I received a letter from Syracuse University. It turned out that a student they had funded had left the PhD program after a few weeks, and they now had funding for me in spring 1988. This was the best news I could have had. In a few months, I was on my way to my first experience of snow in upstate New York! That program was probably also the best thing that ever happened to me. The serendipitous path, from encounters with neurologically challenged children as a schoolgirl leading to an interest in neurons, the white brochure falling into my hands, and ending with the other graduate student leaving the program, formed the basis of my entire career.

Opportunity to Work at House Ear Institute

At the end of my PhD work, cochlear implants were exploding onto the scene, and I badly wanted to work

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on this neural prosthesis. However, Joe Zwislocki was among those who were skeptical of the whole enterprise and questioned the ethics of implanting children without adequate safety tests, all likely reasonable doubts in the early days. As my PhD advisor, he refused to support this "crazy" venture.

But then, another serendipitous thing happened. As it turned out, Joe had always had a soft spot for Bob Shannon (see bit.ly/4dHEysM) ever since the two had met at a conference and spent some hours talking about shared interests in physiology-based models of psychophysical phenomena, and he was impressed by a talk that Bob gave at the 1994 Spring meeting of the Acoustical Society of America. Returning from that meeting, Joe said to me, "If you work with Bob Shannon, I will support your getting into cochlear implants." I didn't know Bob at all, but I sent in an application and was invited to visit House Ear Institute in Los Angeles, California (see hifla.org). Now, another piece of serendipity had to occur, Bob had offered the open postdoc position to someone else, but that candidate had declined, leaving a position open for me. This allowed me the opportunity to work on the first truly successful neurosensory prosthesis.

One's cohort is always crucial to success but particularly so in the apprenticeship years and in early-career phases. A remarkable convergence of brilliant minds occurred during my postdoc and early years as a scientist at House. We shared a great excitement about cochlear implants, and many new ideas and discoveries emerged from the countless animated discussions and debates in the laboratory.

Work at Maryland: Launching Work on Voice and Speech Intonation

After a decade as a postdoc and scientist at House, it was time to move back to a university. The Hearing and Speech Sciences Department (see hesp.umd.edu) at the University of Maryland (UMD), College Park, was to be my next home for a while. As I built the laboratory at UMD, serendipity again changed the course of my career. Shu-Chen Peng (now at the United States Food and Drug Administration [FDA]) joined our group as a postdoctoral fellow. She had a background in linguistics/speech language pathology and had completed her PhD at the University of Iowa, Iowa City, focusing on the perception and production of prosody by cochlear implant patients. Prosody refers to the tone and manner of speaking that conveys information beyond words, e.g., question/statement contrasts or emotion Acoustically speaking, voice pitch and its inflections constitute a primary cue to prosody. Until Shu-Chen's arrival in my laboratory, prosody was of peripheral interest in our laboratory, but this was to change quickly.

Our laboratory had been working on psychophysical studies of voice pitch coding in cochlear implants by measuring the patients' ability to detect and discriminate amplitude-modulated electrical pulse trains. Although normally hearing people are very sensitive to the harmonic structure of voices, cochlear implant patients do not have the same access to the harmonic structure and generally access a weak form of voice pitch from periodicity cues in the amplitude-modulated electrical pulse trains. At that time, this was generally thought to be the case, but there had been no demonstration that amplitude-modulation sensitivity was related to voice perception in cochlear implant patients.

To explore this issue, Shu-Chen designed her own experiments to quantify how cochlear implant patients used voice pitch and other covarying cues to tell questions (rising pitch) apart from statements (falling or flat pitch), using methods that were more rigorous than those she had used before. My studies of amplitude modulation and Shu-Chen's studies of question/statement perception were planned as independent experiments, but a serendipitous discovery changed this.

One day while going over results from Shu-Chen's experiments, I realized that the patients who were having trouble in my psychophysical measures were also the ones having trouble in her speech prosody perception tasks. As a psychophysicist, I had never really expected to find such clear relationships between discrimination measures on single electrodes and speech perception measures from broadband acoustic stimulation. I was truly excited. This led to a collaborative study in which we showed that amplitude modulation sensitivity in cochlear implant patients predicted their utilization of voice pitch cues in speech prosody. Our laboratory became more focused on speech prosody from that point onward.

Work at Maryland: Launching Pediatric Research

Being in a Hearing and Speech Sciences Department meant that my students and postdocs were more interested in translational speech perception studies than in the more basic psychophysics, and this influenced the direction of my research. An early audiology student in our laboratory was interested in speech perception by children with cochlear implants and persuaded me to set up a study for her research project involving children. This small study actually got our laboratory ready to work with children.

As it happened, there was another reason for our laboratory's growing interest in the pediatric population: if we could develop expertise in working with children, we could study the effects of plasticity in children who were congenitally deaf, received cochlear implants within the first year or two of birth, and whose auditory systems were developing with cochlear implants.

I was also becoming interested in how linguistic input might change pitch sensitivity in children who spoke tonal versus nontonal languages. In tonal languages, such as Mandarin, a word can change its meaning based on voice pitch inflections, so hearing these "lexical tones" is crucial for speech. Might children who were immersed in a tonal language and had been implanted early enough to benefit from the greater plasticity of the brain to overcome some of the device limitations in pitch perception? We wanted to ask exciting questions about how developmental plasticity, sensory deprivation, and prosthetic stimulation interacted to shape specific aspects of speech communication in children with cochlear implants. Shu-Chen, who was originally from Taiwan and was now working at the FDA, helped mediate a collaboration with Yung Song Lin's laboratory in Tainan, Taiwan. They were excited about our research questions and happy to work with us. Another student in my laboratory was interested in studying how children with cochlear implants perceived vocal emotions because voice pitch inflections are crucial for spoken emotion identification.

An obstacle presented itself now, in the form of funding. Our primary funding (my R01 grant from the National Institutes of Health [NIH]) was related to psychophysical and speech perception measures in adults with cochlear implants. To pursue work with children, we needed funding; to obtain NIH funding, we needed compelling preliminary data.

Serendipitously, unfortunate events outside our laboratory led us to funding for our work. The United States economy crashed in 2008; the American Recovery and Reinvestment Act legislation passed by the government in response allowed NIH to issue funding for grants that accelerated science. I seized the opportunity to propose an expansion of our laboratory's repertoire to conduct research on psychoacoustic and speech perception studies in children with cochlear implants relating to voice pitch coding and prosodic cue perception.

Fortunately, we were awarded a small two-year grant, which paid for Mickael Deroche's postdoc in our laboratory. Mickael (now at Concordia University, Montreal, Quebec, Canada) led our first psychoacoustic studies investigating fundamental frequency coding in children with cochlear implants. Serendipity had led us to funding that launched our pediatric research program in a serious way. The data collected under that grant formed the basis for larger grants from the NIH. We were able to establish a decade-long collaboration with Lin's laboratory in Taiwan and with Charles Limb's laboratory at The Johns Hopkins University, Baltimore, Maryland, and later at the University of California, San Francisco. We were able to answer key questions about voice pitch coding by pediatric cochlear implant recipients speaking Mandarin, comparing them to those in the United States speaking English. Soon, our studies on vocal emotion perception also started taking off.

Move to Boys Town

After eight years at the University of Maryland, I moved to Boys Town National Research Hospital (BTNRH) in Omaha, Nebraska, and established my third laboratory here. This came about through a string of serendipitous events.

First, Michael Gorga (a pioneering scientist at BTNRH) was invited to give a talk at Maryland, and we got to know each other during that visit. Next, one of the people on Walt Jestead's team (Walt was the Director of Research at BTNRH) applied for a postdoctoral position in my laboratory, but I didn't have funds to support her, and Walt mentioned that a simpler solution might be for me to move to BTNRH, implying that a position there was available if I was ever interested. I had never thought of moving to the Midwest. I responded politely, indicating that I was quite happy at Maryland for the moment. Over time, however, my workload (teaching alongside ever-expanding research commitments) at Maryland started increasing beyond my capacity, the laboratory expanded beyond the space available, and I felt that continuing to be productive on my grants was becoming challenging.

Suddenly, the thought of a job where I could simply focus on my research and interact with some of the greatest minds in our field on a daily basis became a luminous possibility. I asked Walt if the position he had mentioned was still open. It took another year and a half for me to wrap up things at Maryland and move to BTNRH, but I know that Walt and Michael played a key role in making it all happen. Again, if Michael had not visited Maryland and if that individual on Walt's team hadn't applied for a postdoc in my laboratory, perhaps the move to BTNRH would not have come about.

Aging Studies

My laboratory was studying the pediatric population more and more, and BTNRH had deep expertise in working with children. Our work with voice pitch and emotion perception was continuing, but we focused on the pediatric population, with typically hearing children and a group of typically hearing adults who were younger than 35 years of age as controls.

One day, I was looking at the data and was surprised to see one normally hearing adult scoring poorly in our emotion identification task. Digging deeper, I realized that a mistake had been made; that particular adult was 62 years old, not younger than 35 as our protocol required. Looking further, I realized that there was an established literature showing age-related decline in emotional prosody identification in adults with good hearing. This literature was sparse, however, and other than one or two studies, it wasn't clear that audiometric controls had always been carefully made. Discovering that serendipitous error led us to a number of studies investigating the effects of age, hearing loss, and cochlear implantation on spoken emotion perception by adults.

This area of research is now expanding in our laboratory, but soon we will need to secure external funding. I know the pattern by now. Something serendipitous will happen, lines will converge, and exciting things will ensue that I never planned for and didn't imagine. I just must allow the "out of the box" elements their space and time, and the last thing I should do is try to plan and control the path of my work.

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