Enhancing Music Appreciation for Cochlear Implant Users

BY RAYMOND GOLDSWORTHY

There is harmony and rhythm to life that rises in our music as expressions of hope and joy, as well as longing and despair. Music is powerful in many ways, including its ability to comfort and heal. The healing power of music is a hot topic in medicine with leading doctors and scientists around the world using music to aid recovery from disease and trauma. Doctors often work with music therapists to encourage rehabilitation for diseases from Alzheimer's to Zoster, and scientists strive to better understand how music facilitates recovery.

Among ailments, hearing loss is unique in its relationship with music. When we lose our hearing, we want to turn to music for comfort and support, but hearing loss diminishes our ability to appreciate and enjoy music and frustrates our efforts. With great effort, harmony can be restored, vibrant melodies can emerge and a new rhythm can be found that restores the joy of music despite the experience of hearing loss. Cochlear implantation has enabled me to embark on a journey through music appreciation that has been both personal and scientific.

I lost my hearing when I was 13 years old, when I suffered a bout of spinal meningitis, which was treated with ototoxic antibiotics. (Ototoxic meant that the antibiotics killed the sensory cells of my inner ear.) Following a short stay in the hospital, I emerged healthy but in the process of my recovery, I lost all my hearing. Hearing loss at any age is challenging, but I was fortunate to have supportive family members and friends to help me through.

Losing music during this time was harsh. I had recently discovered MTV and was avidly exploring rock 'n' roll and—as a young punk skater—music was integral to my way of life. I had also just started playing drums and was only a year into that study when my hearing loss struck. My friends were sympathetic but only so much could be done to lessen this loss at a time when everyone else was discovering new music.

The year was 1988, and pediatric trials for cochlear implants in the U.S. were underway. With my parents' support, I was an able, willing candidate. I received my cochlear implant (CI) from the Riley Hospital for Children in Indiana with Dr. Richard Miyamoto as the attending surgeon. Activation day was amazing. Sure, nothing made sense; beeps and bops tickled my brain and it would take months for those initial, crude sounds to resolve into meaningful patterns. Fortunately, my mother was an English teacher and she patiently helped me rediscover how to hear. But even as speech comprehension returned, music remained discordant and unrecognizable.

The Sound of Music Returns

At this point in my story, the science behind the scenes started to give me hearing science lessons. The first lesson I learned was that the brain adapts in remarkable ways. Beeps and bops magically became spoken speech and, voila, I could hear again. The sound quality was discordant, but I could understand speech, even—to some extent—in noisy situations. The sound of music, however, remained discordant despite my best efforts.

I was fortunate to learn another science lesson early on, in that technology can always be improved. When I turned 18, the audiology team at Riley Hospital informed me that a new sound processing strategy was available, which they hoped would improve my hearing. Up to that time, the strategies I had been using estimated and encoded specific speech frequencies. Then scientists introduced a new strategy that used a winner-takes-all approach with the strongest frequencies captured and encoded into stimulation. Wow! I remember listening to music the very day I turned on this new technology and thinking that it was going to be a game changer. More generally, this experience taught me that technology may be be improved to complement our own rehabilitation efforts.

Raymond at 14, playing the drum set he received on Christmas day in 1988, the same year he received his CI

I do recognize, and very precisely so, that the acuity of my hearing is less than normal, and this results in some high-level deficits, such as being unable to distinguish major and minor keys. Yet at the most important level, music inspires and motivates me and gives me comfort and a way of adding my voice to the chorus of family and friends who surround me.

As a college student, I was drawn to physics, and as I finished my undergraduate studies, I realized that I could channel my passion for physics into improving CIs. My doctoral thesis focused on improving speech comprehension for CI users in noisy and reverberant environments, a topic that I still work on today. During my post-graduate years, my research gradually shifted from speech to music. This change was accompanied by a renewed passion for music playing as I started playing drums for a garage band. We were awful, but it was an awful lot of fun!

I Became Attuned to Improving CIs for Music

Improving CIs for music requires exploring the basics of hearing in an approach that differs from the one used for improving speech comprehension. With the latter, many of the improvements can be made on the "front end" of the sound processing. Multiple microphones can be used to capture sound, then algorithms can be used to determine where sounds are coming from in space. Sounds can then be selectively filtered to emphasize sound from a desired direction. Substantial work in this area has been completed where cochlear implant or hearing aid users benefit from speech enhancement algorithms on their devices.

Enhancing music perception for CIs requires diving deep into understanding how electrical stimulation produces a sense of pitch for recipients. Pitch refers to the

Backyard jam session–Raymond with his daughter, Jaya, and son, Kesav

quality of sound that gives it "highness" or "lowness" and that supports the formation of melodies. Pitch resolution is poor in CI users compared to people with normal hearing. The smallest difference between musical notes used in a melody is a semitone, or half step, which corresponds to a frequency difference of about 6%. For example, many musical systems tune instruments so that the A4 note is precisely 440 Hz (cycles per second). The A# note above it is 6% higher or about 466 Hz. People with normal hearing can usually hear frequency differences of 1%, and trained musicians can hear changes as small as 0.1%. This remarkable resolution provides nuanced representations of melodies that serve as the foundation of music appreciation.

Cochlear implants convey pitch in two ways. The first way is by stimulating different electrodes. Electrodes that are implanted deeper into the cochlea produce a lower pitch. Scientists are working toward better ways of providing such place cues for pitch through better electrode designs and through better stimulation strategies. The second way of conveying pitch is by the speed of stimulation. The stimulation rate or modulation frequency provides a sense of pitch. Much of my research, as well as other efforts across the world, focus on how to optimally combine place and rate cues for improving the overall sense of pitch that CI users hear.

Today, the best-performing CI users can hear pitch differences of about 1%, so they are right on the range for normal hearing listeners. But the average outcome for CI users is much poorer with pitch resolution of typically 10%. Even in the best case, pitch resolution tends to deteriorate for higher notes. In my research, we often observe a reduction in pitch resolution for notes above middle C (262 Hz). Consequently, melodies are often heard as muffled, and musicians are often frustrated by this lack of resolution. The two hearing science lessons that I learned early on—that the brain can learn to use new information and that technology can be improved—motivate me to continue working on better pitch perception for CI users.

Music Hath Charms

Music appreciation is much more complex than any single feature of music such as pitch. Music taps into our emotions and motivations in a very personal way. Someone can have normal hearing and hate music or be completely deaf and be enraptured by it. Because of this, scientists explore the psychological and sociological aspects of hearing loss on music appreciation. In my opinion, the most important outcome of these psychosocial studies is that they have shown that it is important for people with hearing loss to be confident and persistent as they strive to enjoy music.

Raising Awareness as Well as My Voice

I participate in a music hour that my group organized for people with hearing loss. Students from the University of Southern California's Thornton School of Music bring in a new guest musician each week, and after we listen to a performance, we ask questions and share stories. This type of shared music experience encourages music appreciation. I am looking forward to the pandemic getting under control, so we can restart our in-person workshops, but the virtual component has been wonderful too, and we plan to continue this way. A perk of the virtual format is bringing together people with hearing loss from around the world.

At this point in my hearing loss journey, music sounds rich and natural to me. Music is part of my life and I play guitar for my children every night. After 33 years of CI experience, my hearing is the new normal for me and I am shocked when my scientific colleagues suggest that my music appreciation is somehow less than what it could be. I do recognize, and very precisely so, that the acuity of my hearing is less than normal, and this results in some high-level deficits, such as being unable to distinguish major and minor keys. Yet at the most important level, music inspires and motivates me and gives me comfort and a way of adding my voice to the chorus of family and friends who surround me. HL

Raymond Goldsworthy, Ph.D., received his Bachelor of Science in Physics from the University of Kentucky in 1997 and his Doctor of Philosophy in Health Sciences and Technology from Harvard University and the Massachusetts Institute of Technology in 2005. Ray joined the University of Southern California faculty as an associate professor of otolaryngology in 2014. Ray's research focuses on music appreciation after cochlear implantation. To learn more, send an email to BIONIC-L@USC.EDU.