

TUNING IN TO OUR AMAZING AUDITORY SYSTEM

Nina Kraus leads a diverse team of researchers and clinicians who are teasing apart the way our brains process sounds and finding that auditory ability is a strong indicator of brain health

BY TORI DEANGELIS

As a child, one of Nina Kraus's favorite places to play was underneath the piano, while listening to her mother playing Scarlatti, Scriabin or Brahms.

"I'd bring my toys and little things with me—it just felt good to me to be under there," recalls Kraus, who now directs the Auditory Neuroscience Laboratory at Northwestern University.

Her mother's professional piano playing was just one of the rich and compelling sounds in her childhood. In addition to live music, her home featured the lyrical voices of her European-born parents, who spoke Italian, French and German. Kraus says that those early experiences made such an impression on her that studying how we process sound became her life's work.

"I must have realized that sound was important somehow," says Kraus, who earned a PhD in neuroscience from Northwestern. "My whole career has been looking at our life in sound, for better and worse."

In her lab, Kraus and her colleagues study numerous aspects of the auditory system, including its underlying brain mechanisms, the way musical input influences

our ability to read and learn language and how conditions such as autism, aging and HIV affect sound processing.

In the past few years, the lab has been focusing on the auditory aspects of concussion, resulting in a new five-year grant from the National Institute of Neurological Disorders and Stroke (NINDS) to study this injury in all of Northwestern's Division I athletes, who play football, basketball, soccer, lacrosse, field hockey and more.

"Sound processing is one of the hardest jobs we ask our brains to do because it involves processing on the order of microseconds," Kraus explains. "So, if you get hit in the head, it is really one of the first things to go. You can think of sound processing in the brain as a measure of brain health"—and hence, as an important lens through which to examine concussion, she says.

A key source of data for Kraus and colleagues is the frequency following response, or FFR, which is measured with sensors placed on the top of the head, forehead and earlobes to capture fine-grained electrical signals from auditory areas of the brain in response to a stimulus. The result, read out like an

electroencephalogram, renders a precise reading of the auditory system's neurological activity that actually resembles the pattern of the sound stimulus itself.

"To have the rigor, clarity and objectivity that the FFR provides allows me to feel comfortable and powerful approaching abstract issues," Kraus says. In fact, with additional study, the technique has the wide-scale potential to help screen for and contribute to the diagnosis of conditions like concussion and language disorders, she notes.

AUDITORY NEURODEVELOPMENT

Studying the brain's ability to process sound requires researchers to explore many different auditory dimensions and applications. As a result, Kraus's lab is made up of a diverse mix of scientists, clinicians, engineers, musicians and even athletes.

An example of the lab's basic science is a longitudinal study that aims to shed light on the neurodevelopment of the auditory system in children ages 3 to 8. Using the FFR method, team members have measured 180 children's brain responses to speech, starting at age 3 or 4. The team has found that with





age, children's auditory systems undergo changes that allow them to respond more quickly to speech, to more clearly encode sound details such as pitch and to process sounds more consistently and reliably, explains lab member Elaine Thompson, who is writing her dissertation based on this work. The research also shows that in at least one of these domains—the ability to encode sound details—children develop at different rates.

For her dissertation, Thompson is drawing on these findings to better understand

the development of an important auditory ability: how we hear and understand speech in noisy environments. Past research has shown that this ability—important for many practical reasons, such as hearing a teacher's feedback in a noisy classroom or a coach's instructions on the football field—arises from interactions among the auditory system, cognitive skills and language abilities. As just one example, consider that listening to a friend's voice in a noisy room requires that you focus on the friend's message,

As children grow, their auditory systems change to enable them to respond more quickly to speech, to more clearly encode sound details and to process sounds more consistently, the lab has found.

filter everything else out and temporarily store words as they enter your auditory stream so you can respond meaningfully to your friend.

Thompson is looking specifically at data from the children at ages 5 and 6 to see how these factors intertwine at that age, and in the process, to better understand the factors that support speech-in-noise ability in early childhood. "Disentangling these mechanisms in a normative sample of kids could eventually help improve clinical outcomes for those with difficulty

listening and retaining information,” including children with attention-deficit hyperactivity disorder, auditory processing disorder and language impairments, she says.

CONCUSSION AND ITS CONSEQUENCES

Meanwhile, lab research scientist Jennifer Krizman, PhD, is working to understand the impact of concussion on the auditory system—a keen personal interest for her since both of her brothers played high school football and one continued playing into college.

For part of this work, she is collaborating with Cynthia LaBella, MD, a physician at the Lurie Children’s Hospital in Chicago who works with children who take longer than average to recover from concussion. The two are using the FFR to determine how well these youngsters can understand speech in noise. In a paper in *Scientific Reports* (Vol. 6, No. 1, 2016), Kraus, Krizman, LaBella and colleagues showed that compared with children without a concussion history, these youngsters had an impaired FFR to speech, particularly in relation to the fundamental frequency or pitch of speech sounds.

In another study reported in *Brain Injury* (Vol. 32, No. 6, 2018), children with concussion also did more poorly on tests that required them to repeat sentences that they heard in the midst of noise. As the children’s self-reported concussion symptoms of fatigue and inattention resolved, their FFR patterns returned to nearly the

RESEARCH FOCI

The Auditory Neuroscience Lab at Northwestern University is investigating:

- 1
The neuro-development of the auditory system
- 2
How concussion and other conditions impact the auditory system
- 3
How music training enhances learning



Dr. Nina Kraus, center, with her team at the Auditory Neuroscience Lab.

same level as that of healthy children, the team found.

“Pitch is a really important element for understanding speech in noise—it’s what allows you to lock onto a voice and follow it amid the din,” Krizman explains.

Now, Krizman and colleagues are taking these insights to the football field. For the past two seasons, they’ve been working with the Northwestern football team to assess players’ FFRs before the start of the season and again at the end of it. If a player gets a concussion, he comes in for testing as soon as possible after diagnosis. The NINDS grant promises to enhance this work by enabling testing of many more athletes from a variety of collegiate sports, she adds.

Lab members are excited about other areas with potential real-world applications as well. Travis White-Schwoch, the lab’s senior research data analyst, worked with others in the lab on a project examining the

effects of aging on the auditory system. An analysis of five years’ worth of FFR data showed that older adults’ neural processing of speech in noise declined over time, even when their scores on traditional behavioral tests of auditory ability were normal. But when the team gave this group a computer-based auditory training program, they found they were able to mitigate some of that decline in neural processing (*Proceedings of the National Academy of Sciences*, Vol. 110, No. 11, 2013).

In another project, White-Schwoch is working with an international group of researchers examining how HIV affects the auditory system. Although anti-retroviral medications are highly effective in reducing viral loads, some of these drugs fail to pass into the brain. Hence, says White-Schwoch, “some baby boomers who are HIV-positive and generally very healthy are starting to show faster rates of cognitive decline.”

“We need to bring together the worlds of neuroscience and health care to strengthen our biological knowledge of the use of music to heal and improve well-being.”

NINA KRAUS, PhD, THE AUDITORY NEUROSCIENCE LABORATORY
AT NORTHWESTERN UNIVERSITY

The team is working to develop an auditory test battery that will provide an earlier, more accurate approach to detecting cognitive decline in this population, with the eventual aim of creating related interventions, he says.

MUSICAL FORAYS

A tour of Kraus's lab would not be complete without a look at her work on music. She has been influenced not only by her musical mother but also by her husband, Marshall Dawson, a professional musician and sound engineer. Meanwhile, Kraus herself is an amateur musician who sings harmony and tries her hand at electric guitar, harmonica, drums and piano.

The lab has examined music's impact from several angles. On the basic end, lab members are looking at how people experience and process rhythm—a fundamental characteristic not only of music but of speech as well. They've found, for example, that children who can synchronize to a beat have more precise neural responses to speech sounds and score higher on tests of phonological awareness and language skills than those who aren't as adept at this skill (*Proceedings of the National Academy of Sciences*, Vol. 111, No. 40, 2014).

What's more, the team is

finding that people are capable of at least two different types of rhythmic abilities: tapping along to a beat and remembering and reproducing rhythmic sequences. And, they're finding, individuals differ in how well or if they can perform each type of ability.

What's more, these abilities appear to be linked to different brain capacities: Beat synchronization is related to the subcortical and primary cortical motor regions of the brain and is picked up by the FFR, while rhythmic memory additionally includes motor-planning abilities and is evinced by another electrical brain measure, the evoked cortical response (*Journal of Cognitive Neuroscience*, Vol. 29, No. 5, 2017). Given what is known about brain regions responsible for language, it is also likely that people who are better at rhythmic memory skills tend to excel at language skills as well, the team adds.

On the applied end, they are looking at how music training can improve young people's ability to listen, read and process language. “Music is a tremendous model for learning through sound,” says Kraus. “It does an especially good job of engaging our cognitive, sensory, motor and reward systems, which are crucially engaged in auditory learning.”

FURTHER READING

Individual Differences in Rhythm Skills: Links With Neural Consistency and Linguistic Ability

Tierney, A., et al.
Journal of Cognitive Neuroscience,
2017

Neurobiology of Everyday Communication: What Have We Learned From Music?

Kraus, N. &
White-Schwoch, T.
The Neuroscientist,
2016

Reversal of Age-Related Neural Timing Delays With Training

Anderson, S., et al.
Proceedings of the National Academy of Sciences,
2013

The lab has been studying the long-term impact of a music-training and performance initiative for underserved youth called the Harmony Project, founded in 2001 by University of California, Los Angeles, public health researcher Margaret Martin, DrPH. Martin's aim was to promote positive youth development and social inclusion among low-income children in Los Angeles at risk for delinquency by providing them with free music lessons, instruments and performance opportunities. The project has since gone national, resulting in extensive press coverage and a range of creative performances.

In 2011, Martin began collaborating with Kraus's lab to conduct longitudinal studies on how the project affects young people academically, neurologically and behaviorally. In a randomized controlled trial of 44 children in Los Angeles public schools, the researchers found that music training fostered the children's ability to read at their appropriate age level compared with controls (*Journal of Neuroscience*, Vol. 34, No. 36, 2014; *Annals of the New York Academy of Sciences*, Vol. 1337, No. 1, 2015).

In another study conducted in Chicago public schools, 19 low-income teens who took part

● **To learn more** about the Auditory Neuroscience Lab, visit www.brainvolts.northwestern.edu. The website includes user-friendly demonstrations of research findings from the lab as well as demonstrations of the FFR method, which you can view at www.brainvolts.northwestern.edu/demonstration.php. You can also follow the lab via twitter at @brainvolts and like it on Facebook.

in school-based music training showed greater maturation in the cortical regions of the brain and greater gains in phonological awareness—the ability to identify and manipulate units of spoken language—than 21 peers engaged in nonauditory training (*Proceedings of the National Academy of Sciences*, Vol. 112, No. 32, 2015). The findings also demonstrate that music training can help teens avoid a normal waning in subcortical response consistency—a response to sound that tracks with language skills—and can confer neurological and auditory benefits later in development than was previously thought.

Kraus is also excited about



The lab has found that auditory training can mitigate some of the decline in neural processing among older adults.

her lab's potential to explore an area new to her: research on music therapy, a topic receiving increased attention at the National Institutes of Health and the subject of a conference

held at Northwestern in May that is one of the first efforts to bring together leaders in these two areas (see <https://musictherapy.soc.northwestern.edu>).

“Therapy through music enriches people’s lives, yet there is a gap in our understanding of how it works,” Kraus says. “We need to bring together the worlds of neuroscience and health care to strengthen our biological knowledge of the use of music to heal and improve well-being.” ■

● **“Lab Work”** illuminates the work psychologists are doing in research labs nationwide. To read previous installments, go to www.apa.org/monitor/digital and search for “Lab Work.”

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For Anxiety

For Insomnia

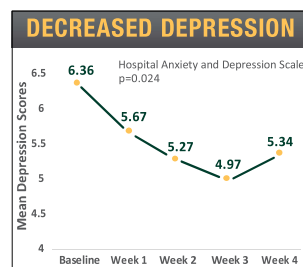
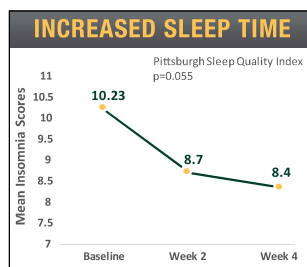
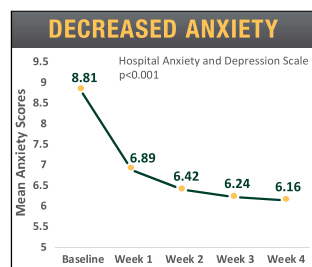
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REFERENCE

Yennurajalingam S, Kang D-H, Hwu W-J, Padhye NS, Masino C, Dibaj SS, Liu DD, Williams JL, Lu Z, Bruera E. Cranial electrotherapy stimulation for the management of depression, anxiety, sleep disturbance, and pain in patients with advanced cancer: a preliminary study. *Journal of Pain and Symptom Management*. 2018 Feb; 55(2): 198-204.



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