

As audiologists, we're frequently interested in how the brain interacts with different sounds. Usually, of course, it's for diagnostic reasons, and our primary question is whether a tone is perceived, or a speech signal is understood. On the other hand, in research, a wide range of perceptions are studied, and often different groups of normal-hearing individuals are compared, such as male vs. female, young vs. old, trained vs. untrained, etc.

And speaking of training—the study of music perception and the brains of those who play music is also a fascinating topic. One of the pioneers in this area was Carl Emil Seashore ("Seashore" is from the translation of his Swedish surname Sjöstrand), who in 1895 obtained the first PhD granted in psychology from Yale, and went on to have a long and distinguished career at the University of Iowa. A student of music (he played the organ and directed the choir for the local Lutheran church), Seashore's interests led him to develop the Seashore Test of Musical Ability in 1919. If you're an audiology history buff, you probably recall that the Seashore Test was used by such notables as Chuck Berlin in the 1960s as part of a central auditory processing battery.

The wave recorder and disk phonograph of Dr. Seashore's time are gone, but research related to music and musicians' perceptions is going strong, particularly at Northwestern University. There, **Nina Kraus**, PhD, Hugh Knowles Professor, (Communication Sciences; Neurobiology and Physiology; Otolaryngology), is investigating learning-associated brain plasticity throughout the lifetime of normal; expert (musicians); clinical (dyslexia, autism, and hearing loss), and animal models.

Dr. Kraus is known to be a pioneering thinker and innovator who bridges multiple disciplines. Her work is not only recognized by audiologists and scientists, but is known internationally by the general public thanks to reports on CNN and NPR, and articles in *National Geographic*, *Nature*, *Science*, and *U.S. News and World Report*, just to name a few. We're proud to add *The Hearing Journal* to the list.

In this article, Nina gives you a glimpse of some of the research from her auditory neuroscience laboratory. To fully appreciate the work that she's doing, you can visit www.brainvolts.northwestern.edu. Maybe those piano lessons your mother made you take weren't such a bad idea after all.

GUS MUELLER
Page Ten Editor

Musical training gives edge in auditory processing

By Nina Kraus



Nina Kraus

1 I understand that you've been doing some research on musicians lately. Are you a musician yourself?

I was raised in a musically rich household, and there's always been music in my home. All three of my sons play various instruments, and I personally play piano, guitar, and drums. So, I guess the answer is yes.

2 What kind of musician research are you working on?

We know that musicians have certain perceptual advantages over non-musicians, such as better auditory attention, memory, and listening skills. In my Auditory Neuroscience Lab at Northwestern University, we've been investigating the effects of musical experience on the nervous system.

I am very excited about this line of research and the progress that we and others have made in demonstrating that music is a resource that tunes the brain for auditory fitness.¹ Lately, we've been looking at the auditory brainstem response (ABR) in musicians with an eye toward determining a biological processing basis for these perceptual advantages.

3 The ABR? I've been using that for years for infant screening, hearing tests, tumor detection, and so on. Why would a musician's ABR be interesting?

The ABRs that have been used in clinical practice for decades indeed do a great job of assessing hearing and afferent central auditory function, and crucially, can do so in individuals. Of course, what makes the ABR extremely valuable in the clinic is that it's an automatic response. In fact, people (and research animals) can have a perfectly normal ABR to a click with a non-functioning cortex. But there's more to hearing than afferent processing. Our experience with sound—how we use it, what we do with it, how it's relevant to us—has far-reaching implications for all levels of the auditory system.

4 You mean the brainstem response changes with experience?

Yes, the brainstem is not just a passive relay station; in fact it's very smart! Experience with music or language, for example, and auditory training change its function. There's even evidence that the response changes in real time, in the course of a single recording session.² So, it's time to stop thinking of the brainstem as a simple waystation. Rather, it's part of our hugely interactive auditory system and, as such, reflects the changes that this complex system undergoes as listening and learning skills change.

5 Experience and training change brainstem processing? How does that work?

Well, as far as we know, the efferent system makes this happen. In the sensory sciences, we're often focused on the afferent system. In hearing, afferent processing is the systematic progression of neural impulses from cochlea to auditory nerve to midbrain and thalamic structures, and finally to auditory cortex. However, there's an extremely extensive network of reverse connections as well.

When a given sound has some importance attached to it, such as the sound of your baby crying, the efferent system, originating in the cortex, strengthens the lower levels' acuity to this sound, all the way to the hair cells in the cochlea. This happens via augmenting stimulus features and increasing the signal-to-noise ratio until the neurons on your auditory system become finely tuned to that particular sound. This cognitive-sensory interaction enables a mother to instantly pick out her baby's cry from among all the other babies fussing at day care.

6 So you could use a baby's cry for the stimulus instead of a click?

You're probably joking, but yes, and we actually have done just that. But the real point isn't what the exact stimulus is; but rather that it's a sound that's more complex and, crucially, more meaningful than a tone or a click.

Think of it this way: A click isn't a very interesting sound and you've probably not had a whole lot of exposure in real life to the clicks that you hear in clinical ABR testing. So from that point of view, the click is an ideal stimulus for assessing hearing; it's a great equalizer. No matter who you are, if you have normal peripheral hearing, your afferent auditory system is going to chug away and produce a response to a click that's going to look pretty much the same as the next guy's.

But what if you are first violinist for the Chicago Symphony Orchestra? If you've reached that stage of your musical career, you've had tons of

experience listening to, absorbing, thinking about, performing, and living the violin. Given all that experience—and the efferent superhighway at your brain's disposal—it would be shocking if your sensory mechanisms *weren't* fine-tuned to the sound of a violin. And this fine-tuning includes brainstem structures that we can measure with techniques that aren't dissimilar to click ABR testing.

7 I'm betting you've studied the brainstem response to a violin note. What does it look like?

You're right, and it looks like a violin note! If you view a violin sound in a sound editor or on an oscilloscope, it's a signature shape. The brainstem response very closely mimics that shape. In fact, if you take a brainstem response recording evoked by a musical note or a syllable, you can aurally play it through a loudspeaker and the recorded response will be more or less recognizable as the stimulus. This property, in my opinion, reveals much about auditory processing. By comparison, single neuron and cortical response measures are much more abstract representations of the stimulus.

8 So, if the ABR doesn't match the stimulus, the brainstem isn't functioning properly?

Well, that's an oversimplification. It's not really a perfect match because the brainstem has a low-pass filter characteristic that prohibits it from locking on to frequencies much higher than 1000 Hz or so. But within its range of operation, and allowing for inherent auditory system nonlinearities, the response fidelity is quite good. And, a response that hews closely to the sound input indeed signifies high-fidelity processing.

9 What about the traditional Waves I through V that we use clinically?

To a complex stimulus, those waves are there, too, at response onset, and they're very important. The precision and timing of these waves is crucial to a well-firing brainstem. But they are dwarfed by the frequency following response

(FFR), which is time-locked to the cycles of the oscillation in the stimulus. It's the FFR that drives the stimulus-to-response resemblance.

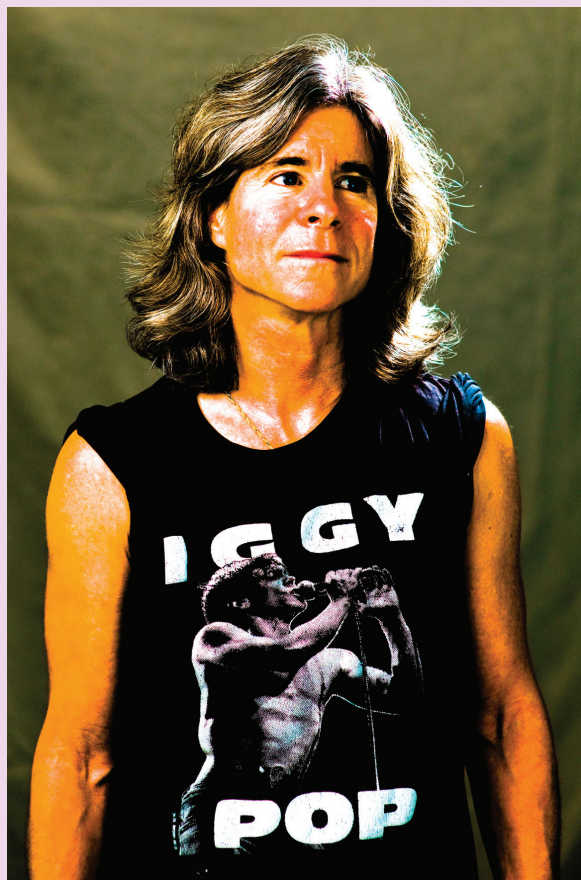
10 So, a brainstem response to a complex sound has a lot more going on than a click response?

Indeed. That brings up a very important quality of the brainstem-evoked response. The response to a complex sound is as complex as the sound itself. As such, much like the stimulus, it can be viewed on several time scales and, loosely, described on three dimensions.

I mentioned the onset response, but there's also an offset response—signaling the sound's cessation. Together with responses to other transients within the stimulus, these peaks represent timing cues that define the temporal envelope of the response. If the stimulus is a musical note, a vowel, or some other periodic, harmonic sound, you can focus on the periodicity of the FFR.

As in the stimulus, the period of the repeating cycles largely determines the pitch of the sound, and this is carried through in the periodicity of the response. Zooming in further, the squiggles and bumps within one periodic cycle define the harmonics. The harmonics distinguish a violin from an oboe, an "ee" from an "oo," or a "ba" from a "ga." Thus, both the stimulus and the response are defined by the three properties of timing, pitch, and harmonics.

A powerful characteristic of the brainstem responses is that these properties of the stimulus are encoded in the response in a separable manner. We don't see a volume-knob effect; there might be enhancement or diminishment on one aspect of the response but not another. This is a key to the power of the brainstem response as a window into subcortical processing. Jack might have deficient timing but normal pitch and harmonics encoding to a complex sound. But Jill might have superior harmonic encoding but run-of-the-mill pitch encoding and typical timing.



Could this be a musician? If so, it's very possible that she has certain perceptual advantages over non-musicians, such as better auditory attention, memory, and listening skills.

11 That's a lot to digest, but while I'm thinking about it—at which response dimension do musicians excel?

We are discovering a variety of things about the musician brainstem response. To the best of my knowledge, we were the first to find a musician effect in the brainstem—response timing was faster and FFR magnitude was enhanced to a cello note, relative to non-musicians' responses.³ In this same study, we also used the syllable “da” to evoke brainstem responses, and musicians showed similar processing enhancements.

12 Wait, speech, too? I can understand a musician having a processing boost to musical sounds, but why speech?

Right, I'm sure you're thinking that musicians probably don't have more experience hearing speech than anybody else. That's really interesting to me, and where the implications have the potential to be far-reaching.

Here is what I think is going on, a musician, such as an instrumentalist in an orchestra, has to be able to keep track of all the other sounds around him, listen for cues, pick out individual lines, and hear his own instrument as it

mixes with all the other instruments. All these tasks are forms of stream segregation, or, said another way, object formation.

A particular sound of interest—say that of your own trumpet—is a stream of notes that forms a unique auditory object. This ability to pull the desired signal from the noise is a type of auditory attention, and we have found that auditory attention skills are particularly good in musicians.⁴

13 And attention is also good for . . . ?

Speech-in-noise perception! The ability to selectively focus on an auditory object has a real and important application outside of music. Wringing the most information possible out of a stream of sounds—embedded in many other often similar and louder sounds—is the definition of what's going on when listening to your dinner companion in a noisy restaurant or a teacher in a classroom.

14 So, are musicians really better at hearing speech in noise than non-musicians?

This seems to be the case, along with advantages in auditory working memory, and a host of cognitively loaded perceptual abilities that have been studied over the years.⁴ We recently demonstrated that instrumentalists, whom we defined as those with at least 10 years of instruction and who are currently practicing at least three times per week, are better at standardized tests of speech perception in noise than non-musicians.⁵ I should mention that in all of our studies, except for those that explicitly address hearing loss, we've very strict requirements for normal and audiometrically matched hearing. So we're dealing with central processing of sound.

15 We've strayed away from neurobiology a little. What happens in the brainstem of a musician, particularly when presented with speech in noise?

Their response holds up better in noise. Remember I mentioned that the brainstem response is less abstract than the cortical response to the same stimulus? Well, one analytical technique that this property allows is a direct comparison of the stimulus to the response via correlation.

In a study of adult musicians, we found that responses from all of our participants—musicians and non-musicians alike—had about the same degree of similarity to the evoking stimulus, the syllable “da,” when it was presented at a comfortable suprathreshold level in quiet. But when we added background babble, typical of what you might encounter in a noisy restaurant, the response in musicians maintained a high degree of stimulus/response similarity. In other words the correlations remained high.

However, in non-musicians, the response morphology suffered, resulting in lower correlation values.⁶ And, to tie it back into speech-in-noise perception, the extent to which an individual's response correlated with the stimulus when presented in noise was directly related to that individual's performance on a standardized speech-in-noise test.

I believe that this ability of the brainstem to latch onto a stimulus and take advantage of stimulus regularities is directly related to facility in object formation and, in turn, to our ability to track our friend's voice and follow a conversation despite the din of noise all around us.

16 So, music- and speech-evoked responses are enhanced in musicians; what else?

Remember the crying baby? We've found a musician enhancement to this non-speech vocal sound, too.⁷ So it does really seem that music training has far-reaching effects in sound processing. But, as interesting as music training's role in developing listening skills may be, something that is equally exciting is what our work in the brainstem has told us about literacy and reading, and how music may affect these realms.

17 Now you've gotten my attention. I know I've heard that music is good for the brain and helps school children learn better. Is this what you're studying?

We have a longitudinal study underway with public school students whose school's curriculum has a strong music education component. We will be following these kids throughout their high school careers. It's still too soon to tell what we'll find since the study is just getting off the ground; however, we have discovered a lot about reading ability and the brainstem, and there are some compelling parallels between brainstem properties in musicians and in dyslexics.

Remember, I mentioned the separability of components of the response? Some response features that are impaired in poor readers are the very features that are enhanced in musicians. Of course, there's a difference between a lifetime of training that a musician goes through and the type of music instruction that a child receives in even a good public school. However, we're learning that the brainstem response is malleable to training on short-time scales, too. For example, we have observed enhanced pitch tracking—the ability of the brainstem to process changing voice pitch—after just a couple weeks of training.⁸ And, we have

demonstrated that the response to the same sound can differ according to its immediate context.⁹

18 So, the implications of this are?

Music training in schools might engage attention and memory skills, which in turn, via the corticofugal efferent system, would engender more precise tuning of the incoming signal in the brainstem. This would lead to an internal, neuronal, increase in signal-to-noise ratio, which would lead to better and stronger phonological processing, leading to better reading skills. Thus, there's a parallel. Both music and reading involve mapping sounds to meaning. That's a sketch of our thinking, anyway, and we have modelling data that support this idea.

19 Music in schools is the answer?

Well, it certainly can't hurt. Music's value is enormous on any number of levels, and whether or not it helps our kids become better readers there's no question in my mind, as a scientist, a musician, and a mom, that music should absolutely be something that's available to every kid. And the public school system is the most logical place to make this happen.¹

20 This is all fascinating. Where can I find out more about your work?

You can visit my lab's website at brainvolts.northwestern.edu. In particular, click on "lab projects" where you can learn more about neural processing in various populations and settings. You will also find some slide shows and links to the articles I've mentioned here as well as additional publications on biological bases of music, speech-in-noise perception, and training.¹⁰⁻¹²

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Deaf Leppard Blog



For more on musicians and hearing, check out *HJ's* Deaf Leppard blog at thehearingjournal.com. There, Marshall Chasin, AuD, Director of Auditory Research at the Musicians' Clinics of Canada in Toronto, blogs about his work fitting musicians with hearing aids that can handle both speech and music as an input.