Identifying Neural Signatures of Auditory Function

By Nina Kraus, PhD, & Samira Anderson, AuD, PhD

When we conduct a clinical assessment, we look for an outcome that corresponds to a specific diagnosis. An assessment yields results consistent with different pathologies.

For example, the audiogram can point to conditions such as otosclerosis, Meniere's disease, presbycusis, noise-induced hearing loss, or vestibular schwannoma, depending on the type and configuration of the hearing loss.

The auditory brainstem response (ABR) can be similarly informative, presenting patterns that reflect conductive hearing loss, sensorineural hearing loss, auditory neuropathy, or lower or upper brainstem dysfunction.

Along these lines, the auditory brainstem response to complex sounds (cABR) yields patterns of findings that are consistent with auditory expertise or impairment. These different patterns can be viewed as specific neural signatures, as defined in Nina Kraus and Trent Nicol's chapter in the 2014 *Perspectives on Auditory Research* handbook, "The Cognitive Auditory System: The Role of Learning in Shaping the Biology of the Auditory System" (In: Popper AN, Fay RR, eds. Springer New York; 299-319).

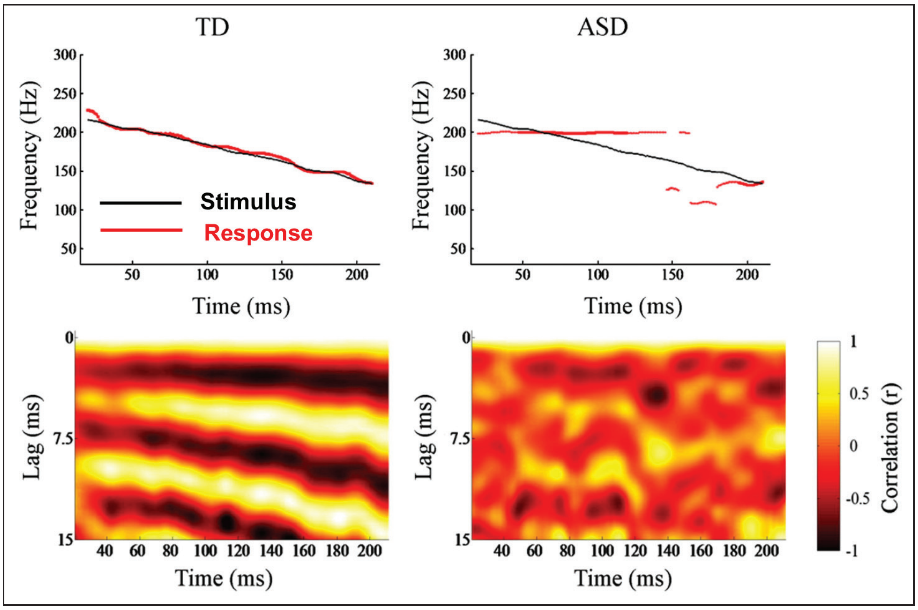

Figure. Top panels: Brainstem pitch tracking (red) aligns well with a falling pitch stimulus (black) in the child who is typically developing (TD), left, but not in the child who has autism spectrum disorder (ASD), right. Bottom panels: Through autocorrelation, the strength of phase locking to pitch is depicted over time. Compared with the child showing normal phase locking on the left, the child with ASD on the right exhibits no consistent pattern of accurate pitch encoding over time. (Modified from *Clin Neurophysiol* 2008;119[8]:1720-1731, with permission from Elsevier.)

For example, children with language-based learning impairments have delayed neural timing and reduction of the first formant harmonics (*Cereb Cortex* 2009;19[11]:2699-2707; *Ear Hear* 2005;26[5]:424-434). Lower intertrial response consistency is also a characteristic of impaired reading ability (*J Neurosci* 2013;33[8]:3500-3504).

Dr. Kraus is a professor of auditory neuroscience at Northwestern University, investigating the neurobiology underlying speech and music perception and learning-associated brain plasticity. **Dr. Anderson** is an alumna of Dr. Kraus's Auditory Neuroscience Laboratory and assistant professor in the University of Maryland Department of Hearing & Speech Sciences, where she is studying the effects of hearing loss and aging on neural processing in older adults.

Children who experience linguistic impoverishment as they grow up may also have decreased response consistency, reduced representation of the harmonics, and increased neural noise compared with children who grow up in linguistically rich environments.

A person's neural signature reflects his or her collective experience with sound throughout life. A given person may be both linguistically impoverished and bilingual.

Other aspects of the cABR relate to different kinds of communication or language impairments. For example, the ability to hear in noise is aided by hearing cues that enable the listener to focus on a single talker among several talkers or noises.

Neural Signatures	Fundamental frequency	Pitch tracking	Harmonics	Onset timing	Formant timing (consonants)	Response consistency	Neural noise (spontaneous rate)
Enrichment							
Music		+	+	+	+	+	
Bilingualism	+	+				+	
Communication difficulty							
Hearing in noise	–				–		
Dyslexia			–	–	–	–	
Autism		–		–			
Linguistic deprivation				–		–	–
Aging	–		–	–	–	–	–

Table. Neural signatures differ for enhanced or impaired auditory function. Enriching life experiences result in improved auditory function in the areas marked with a "+" symbol in the top two rows. Communication difficulties are associated with impairments in areas marked with a "-" symbol in the bottom five rows. (Modified from Kraus N, Nicol T. The Cognitive Auditory System: The Role of Learning in Shaping the Biology of the Auditory System. In: Popper AN, Fay RR, eds. *Perspectives on Auditory Research.* New York, NY: Springer; 2014:299-319, with permission from Springer Science+Business Media.)

Although children with dyslexia have equivalent representation of the fundamental frequency (F_0) compared with children who are typically developing, children who have poor performance on tests of hearing in noise have reduced representation of the F_0 (*Hear Res* 2010;270[1-2]:151-157).

This reduced processing of the F_0 is also seen in young and older adults who have poorer speech-in-noise performance (*J Cognitive Neurosci* 2011;23[9]:2268-2279; *Ear Hear* 2011;32[6]:750-757).

The cABR can measure changes in the F_0 over time, yielding a measure of pitch tracking. Accurate perception of changes in pitch helps the listener understand the intent of the message–i.e., "how" the speaker means the message, rather than what the speaker means.

Impaired pitch-tracking ability may be one of the factors underlying autistic children's difficulty understanding the emotional content of speech (*Clin Neurophysiol* 2008;119[8]:1720-1731). The figure on page 38 shows impaired pitch tracking in a child with autism compared with normal pitch tracking in a typically developing child.

Aging also results in pervasive delays across nearly every measure of the cABR, accounting for the older person's communication difficulties even when the audiogram is clinically normal.

SIGNATURES OF AUDITORY EXPERTISE

So, we see that the cABRs obtained in patients with different impairments have characteristic patterns or neural signatures. Specific neural signatures are also seen in people with auditory expertise, such as musicians or bilingual language speakers.

Musicians have greater representation of the harmonics, earlier peak timing, and increased response consistency compared with nonmusicians, and these effects are seen across the life span (*Hear Res* 2014;308:109-121).

In contrast, bilingual speakers have enhanced representation of the F_0 rather than the harmonics, and increased response consistency compared with monolingual speakers (*Proc Natl Acad Sci U S A* 2012;109[20]:7877-7881; *Brain Lang* 2014;128[1]:34-40).

Selective attention to a specific language may underlie these neural-processing advantages in bilingual speakers; perception of the F_0 is an important ingredient in the ability to group a series of sounds into an auditory object representing linguistic content from a specific language (*Ear Hear* 2011;32[6]:699-707; *J Neurolinguistics* 2010;23[1]:81-95).

Given these diverse neural signatures, we would not expect to look for a single abnormality when using the cABR as a diagnostic tool for communication impairments. Rather, we should look for patterns consistent with the presenting symptoms of the patient.

A person's neural signature reflects his or her collective experience with sound throughout life. A given person may be both linguistically impoverished and bilingual.

Information regarding the patient's history with sound should be considered when developing a management plan. See the table for a summary of patterns associated with different types of auditory expertise or impairment.