

Neural Markers of Listening in Noise

By Nina Kraus, PhD, and Travis White-Schwoch

Noise is an insidious but ubiquitous constraint on our ability to understand speech. Difficulty understanding speech in noise is one of the most common complaints audiologists have to confront, but the audiogram is not a good predictor of listening-in-noise abilities. Many individuals with clinically normal hearing complain of difficulty understanding speech in noise, and even among listeners with hearing loss, individuals with similar audiometric configurations may exhibit different listening-in-noise abilities.

Understanding speech in noise is one of the hardest tasks for the brain (see the editorial in this issue). Finely tuned molecular machinery in the cochlea has to pick up incoming sounds and digitize them into neural signals for the brain to decode. But the ear indiscriminately sends sounds to the brain, which has to tease apart the message from the noise. Cognitive abilities such as working memory and attention are crucial pieces of decoding these acoustic puzzles.

But when we try to understand speech in noise, it can be difficult to know where to start in a clinical evaluation. The frequency-following response (FFR) is a measure of synchronous neural activity in response to sound that is generated predominantly by the auditory midbrain, a highly metabolic nexus for the biological and cognitive mechanisms that mediate listening-in-noise skills. There is good reason to think then that the FFR could be part of a listening-in-noise evaluation.

Here we review evidence that aspects of the FFR align with listening-in-noise skills. Together, this body of work supports the FFR as an objective test of an individual's ability to understand speech in noise. This work is summarized in Table 1. This table also includes references to the work discussed below.



Dr. Kraus, left, is a professor of auditory neuroscience at Northwestern University, investigating the neurobiology underlying speech and music perception and learning-associated brain plasticity. Mr. White-Schwoch is a data analyst in the Auditory Neuroscience Laboratory (www.brainvolts.northwestern.edu), where he focuses on translational questions in speech, language, and hearing.

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FFR MARKER 1: THE FUNDAMENTAL FREQUENCY (F0)

What is it? The fundamental frequency (F0) is the lowest dominating frequency of a sound that conveys the perception of pitch. For example, male voices tend to have lower F0's than female voices. The F0 is a crucial cue for picking a sound out from the din and tracking it.

FFR-F0 and Listening in Noise:

- Individuals with stronger FFR-F0's perform better on clinical tests of hearing in noise. These correlations have been observed in children, young adults, and older adults.
- Changes in the FFR-F0 parallel changes in listening-in-noise abilities. This pattern has been observed developmentally (the maturation of children's FFR-F0 follows a parallel trajectory as the maturation of their listening-in-noise performance) and through auditory training (young adults who underwent LACE™ training improved on their FFR-F0 and listening-in-noise performance).
- Clinical populations with poor listening-in-noise performance show poor F0's. As discussed in recent *Hearing Matters* columns, the FFR-F0 is diminished in individuals who have suffered a concussion. This is noteworthy because many people with concussions or more severe traumatic brain injuries struggle to understand speech in noise.

FFR MARKER 2: CONSONANT TIMING

What is it? Consonant-to-vowel transitions in speech involve rapid changes in frequency over a short period of time, making them difficult to perceive—especially in noise, which covers

Table 1. Summary of FFR Markers of Listening-in-Noise Abilities

FFR Marker	Evidence for a link to listening in noise	References
Fundamental frequency (F0)	<p>FFR-F0 correlates with performance on listening-in-noise tests.</p> <p>Changes in the FFR-F0 parallel changes in listening-in-noise performance.</p> <p>Clinical populations with poor listening-in-noise performance have poor FFR-F0's.</p>	<p>Children: Anderson et al. (2010) <i>Hear Res</i></p> <p>Young adults: Song et al. (2011) <i>J Cogn Neurosci</i></p> <p>Older adults: Anderson et al. (2011) <i>Ear Hear</i>; Anderson et al. (2013) <i>Hear Res</i></p> <p>Child development: Thompson et al. (2017) <i>Hear Res</i></p> <p>Auditory training: Song et al. (2012) <i>Cereb Cortex</i></p> <p>Concussion: Kraus et al. (2016) <i>Sci Rep</i>; Kraus et al. (2017) <i>Neurosci Lett</i></p>
Consonant timing	<p>FFR consonant timing correlates with performance on listening-in-noise tests.</p> <p>Training that improves FFR consonant timing also improves listening-in-noise abilities.</p> <p>Clinical populations with slow FFRs to consonants in noise struggle to listen in noise.</p>	<p>Anderson et al. (2010) <i>J Neurosci</i>; Hornickel et al. (2009) <i>PNAS</i></p> <p>Auditory training: Anderson et al. (2013) <i>PNAS</i></p> <p>Music training (reviews): Kraus & White-Schwoch (2016) <i>Neuroscientist</i></p> <p>Older adults with normal hearing: Anderson et al. (2012) <i>J Neurosci</i></p> <p>Children with learning disabilities: Banai et al. (2009) <i>Cereb Cortex</i></p>
Stimulus-response correlation	<p>FFR stimulus-response correlation correlates with performance on listening-in-noise tests. Expert listeners have stronger stimulus response correlations and excel at listening-in-noise tasks.</p> <p>Clinical populations with poor stimulus-response correlations struggle to listen in noise.</p>	<p>Anderson et al. (2011) <i>Ear Hear</i></p> <p>Kraus & White-Schwoch (2016) <i>Neuroscientist</i></p> <p>Cunningham et al. (2001) <i>Clin Neurophysiol</i></p>

consonants more than vowels. Characteristic peaks in an FFR that reflect the consonant transition can be identified, with the idea that the quicker the brain picks up on these cues, the more robust these cues are processed.

FFR Consonant Timing and Listening in Noise:

- Children with faster FFRs to consonants in noise perform better on clinical tests of hearing in noise.
- Training to speed up FFRs to consonants in noise parallels improvements in listening-in-noise skills. This has been observed following short-term auditory training and longer-term experiences like music training.
- Clinical populations with slow FFRs to consonants in noise are well known to struggle with understanding speech in noise. These populations include older adults with normal hearing and children with learning disabilities.

FFR MARKER 3: STIMULUS-RESPONSE CORRELATION

What is it? Unlike other measures of neural function, the FFR physically resembles the stimulus. In fact, when an FFR is sonified and played back by a speaker, you can recognize the evoking sound (see a demonstration [online](#)). Consequently, an individual's FFR can be correlated to the stimulus to get an overall gauge of the accuracy of neural processing.

FFR Stimulus-response Correlation and Listening in Noise:

- Older adults with stronger stimulus-response correlations perform better on clinical tests of hearing in noise.
- Expert populations with superior listening-in-noise abilities, such as musicians, have stronger stimulus-response correlations.
- Clinical populations with poor listening-in-noise abilities, such as children with learning disabilities, have poor stimulus-response-correlations.

Unlike other measures of neural functions, the FFR physically resembles the stimulus.

AN FFR TEST FOR LISTENING IN NOISE

Together, these lines of evidence support the idea that the FFR reflects biological activity pertinent for understanding speech in noise. Work is underway to develop a fast and easy-to-use protocol that takes an individual's FFR and combines these three ingredients into a score that can indicate listening-in-noise abilities. 