Hidden hearing loss with envelope following responses (EFRs): The off-frequency problem

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Hidden hearing loss with envelope following responses (EFR): The off-frequency problem

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Introduction

Recent animal studies have shown that noise over-exposure can cause the loss of auditory nerve (AN) fiber synapses without causing hair cell loss (see Kujawa and Liberman (2015) for a review). This AN fiber synapses loss has been termed “hidden hearing loss” or “synaptopathy”, since it is not reflected in the traditional pure-tone threshold. The envelope following response (EFR) has been proposed as a potential objective method to assess synaptopathy in humans (i.e., Bharadwaj et al., 2015). Encina-Llamas et al. (2016) reported different trends in EFR level-growth functions recorded using two modulation depths in normal-hearing (NH) and mild hearing-impaired (HI) listeners. The EFR is a gross encephalographic potential that represents the encoding of the envelope of the stimulus, arisen from synchronized neural activity from all excited frequencies and fibers. In this study, a computational model of the AN was used to investigate the effects of off-frequency contributions (i.e. away from the characteristic place of the stimulus) and the differential loss of different AN fiber types on EFR level-growth functions.

Methods

- Computational AN model:
  - Humanized AN model (Zilany et al., 2016).
  - 200 characteristic frequencies (CF), ranging from 0,2 to 20 kHz.
  - Synapses per IHC are simulated by several independent computations of each AN CF (about 500 per CF). Synaptopathy is simulated by computing less of such independent computations.

- Levels:
  - EFR level-growth: 5 to 100 dB SPL, 5 dB steps.
  - Stimulation: 2000 Hz (J = 93 Hz as in Encina-Llamas et al. (2016)).
  - Modulation:

- Mild hearing-impaired: AN fiber method synaptopathy
  - Stimuli: 1000 Hz (J = 93 Hz as in Encina-Llamas et al. (2016)).
  - Modulation: 10-90 dB SNR, 5 dB steps.

- Stimulated with high intensity SAM tone. Differences between NH and mild HI due to OHC dysfunction.

Figure 1: Simulated EFR level-growth functions for the mild-HI group in Encina-Llamas et al. (2016). The group averaged audiogram is fitted assuming 2/3 of OHC dysfunction and 1/3 of IHC dysfunction.

Figure 2: Simulated EFR level-growth functions with a 60% loss of medium- and low-sensory rate (SR) AN.

Figure 3: Simulated EFR level-growth functions with the same ANF loss as in Fernandez et al. (2015). Adapted from the noise to the human cochlea.

Figure 4: Simulated EFR level-growth functions to match the response from the NH group in Encina-Llamas et al. (2016).

Synaptopathy:

- AN tuning curves stimulated with high intensity SAM tone.
- Differences between NH and mild HI due to OHC dysfunction.

Figure 5: Simulated EFR level-growth functions for the mild-HI group in Encina-Llamas et al. (2016). The group averaged audiogram is fitted assuming 2/3 of OHC dysfunction and 1/3 of IHC dysfunction.

Figure 6: All tuning curves simulated with a high-intensity SAM tone. Differences between NH and mild HI due to OHC dysfunction.

Figure 7: Simulated EFR level-growth functions to match the response from the mild-HI group in Encina-Llamas et al. (2016).

Conclusion

- EFRs at high stimulus levels are dominated by the off-frequency contributions.
- EFRs are dominated by the responses from high-SR fibers.
- EFR level-growth functions from synaptopathic frequencies in exposed mice show similar trends to EFR functions in some NH human listeners.

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