Neural processing of the amplitude envelope of sound: Linear or nonlinear?

Bertrand Delgutte

Eaton-Peabody Laboratory, Massachusetts Eye & Ear Infirmary, Boston, MA 02114
Research Laboratory of Electronics, MIT, Cambridge, MA 02139
Bertrand_Delgutte@meei.harvard.edu

Accurate transmission of amplitude modulations in the temporal envelope is essential for the perception of speech and other natural sounds. Dau and his colleagues have developed a model for effective signal processing by the auditory system that accounts for a wide variety of psychophysical data on masking and speech intelligibility. A key component of this model is a bank of linear bandpass filters operating upon the amplitude envelope at the output of each frequency channel formed in the cochlea. While the model does not specify a site for the modulation filter bank, the inferior colliculus (IC) is an attractive possibility because it is the first site where the rate responses of a majority of neurons are tuned to the modulation frequency. We will present three lines of evidence based on single-unit recordings indicating that envelope processing in the IC is highly nonlinear, in contrast with the model’s assumption of a linear filter bank.

1. While a model incorporating a linear neural modulation transfer function (MTF) based on responses to sinusoidal modulations accurately predicts temporal response patterns to a speech utterance in the auditory nerve and cochlear nucleus, this is not the case for the IC.

2. Speech perception typically occurs in rooms, where reverberation degrades modulations in the amplitude envelopes of the signals reaching the ears. We show that responses of IC neurons to sinusoidal amplitude modulations cannot be predicted by a linear convolution of the neuron’s MTF and the room impulse response.

3. In ongoing experiments motivated by a recent psychophysical study (Laback & Majdak, PNAS 105:814-7), we find that introducing random temporal jitter to a periodic pulse train can greatly enhance the ongoing responses of IC neurons at high pulse rates (> 300 pps) in both normal hearing animals and deaf animals electrically stimulated through cochlear implants. This enhancement may partly reflect additional envelope modulations created internally through filtering either in the cochlea (for normal hearing animals) or in the brainstem (for implanted animals).

These results show that some of the complexity described by Schreiner in the cortical processing of temporal modulations is already observed at the midbrain level. Together, these results raise the question of how the highly nonlinear processing of the temporal envelope observed in individual IC neurons is transformed into more linear processing at the behavioral level as implemented in the effective signal processing model. A revised model incorporating some of the nonlinearities observed in IC neurons might yield even better predictions of psychophysical performance.