

Quantifying the effects of the cochlear amplifier on temporal and average-rate information in the auditory nerve

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An active mechanism referred to as the cochlear amplifier is believed to be responsible for sharp tuning and excellent sensitivity in the normal auditory system, and is impaired or absent in many common forms of sensorineural hearing loss. The cochlear amplifier is thought to benefit normal-hearing listeners, especially in complex listening environments in which hearing-impaired listeners have difficulty even with hearing aids.

A modeling approach was developed to relate nonlinear physiological response properties associated with the cochlear amplifier to human psychophysical performance. Quantitative methods combined analytical and computational population models of the auditory-nerve (AN) with statistical decision theory to evaluate performance limits imposed by the random nature of AN discharges (modeled by a nonstationary Poisson process). A new theoretical approach was developed to predict performance for psychophysical tasks that use random-noise stimuli to mask signal information. The ability of temporal and average-rate information in the AN to account for human performance was evaluated for several listening tasks for which the cochlear amplifier has been suggested to be significant.

The benefit of the cochlear amplifier for extending the auditory system's dynamic range was evaluated in terms of AN information available for encoding changes in stimulus level. An analytical model included nonlinear gain, level-dependent phase, and high-, medium- and low-spontaneous-rate AN fibers. It was shown that the physiologically vulnerable cochlear amplifier is beneficial for robustly encoding sound level within narrow frequency regions based on nonlinear phase responses at low frequencies and nonlinear gain responses at high frequencies. A physiologically realistic mechanism to decode nonlinear gain and phase cues is monaural, across-frequency coincidence detection. Level-discrimination performance of a coincidence-counter population matched human performance across the entire dynamic range of hearing at both low and high frequencies. The demonstrated benefit of the cochlear amplifier for the robust encoding of sound level within a narrow frequency region is particularly important for complex stimuli, where spread of excitation is not possible, and is consistent with the common finding that hearing-impaired listeners have the most difficulty in complex listening environments.

The cochlear amplifier alters tuning within the normal auditory system based on the spectral and temporal configuration of the stimulus. A computational AN model was used to demonstrate the effects of suppression, a property associated with the cochlear amplifier, on psychophysical measures of auditory frequency selectivity. Specifically, psychophysical auditory-filters derived from the nonlinear AN model with suppression were broader than the low-level peripheral model filters. In addition, there was a frequency-dependent bias in psychophysical estimates of auditory filters due to the increase in cochlear-amplifier gain with frequency. Understanding the effects of cochlear nonlinearity on psychophysical estimates of human frequency selectivity is important because of the wide-spread use of these filter estimates in auditory models and in evaluating the abilities of hearing-impaired listeners.