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A Functional Model of the Auditory Peripheral System

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Most long-standing theories of speech perception in general have emphasized the important role of neural structures within the cerebral cortex in normal language processing (Pont, 1991). If we understand fully the nature of speech perception - whether for reasons of scientific curiosity, to help in the prevention and treatment of various hearing disorders, or to assist in developing powerful speech recognizers - then the role of this processing must be investigated. To explore the representation of speech in the cortex via the brain-stem nuclei, e.g., the cochlear nucleus, computer simulation is used as one of the useful methods. A model of the brain-stem nuclei for studying its sophisticated functions must include procedures for dealing with action potentials and produces action potentials that can be compared with those from actual physiological experiments. Action potentials must also be prepared as inputs to the model of the brain-stem nuclei. This paper presents a functional model of the auditory peripheral system for obtaining input impulse trains to the brain-stem nuclei. The models of the external ear, middle ear, BM and OHC used in this study are based on the work of Giguère and Woodland (1994). They consist of a concatenation of electrical circuit submodels, and were implemented by applying the techniques of mesh analysis, Laplace transformation and bilinear transformation. The IHC model proposed by Meddis (1986, 1988) is extended by modifying the membrane permeability as a function of amplitude of the BM velocity which is the output of the cochlear network. This model can simulate nonlinear transducer functions of the IHC, which are depolarized and hyperpolarized peak responses as a function of the peak sound pressure level and the DC components of the receptor potential as a function of the stimulus level. The auditory nerve (AN) model is proposed using Hodgkin's cell membrane model (1952) to generate a spike train and to model the spike discharge pattern directly. These models are combined into a functional model of the auditory peripheral system. Response patterns of the auditory peripheral model were evaluated in detail (Maki and Akagi, 1996, 1997). That is to say, output of the functional model is compared with various physiological experimental data i.e., the responses of rapid and short-term adaptation, recovery from adaptation, recovery of spontaneous activity, and response changes to intensity etc. The test of rapid and short-term adaptation shows that the short and rapid components for individual model fibers are in quantitatively agreement with those of the physiological data by modifying the membrane permeability of the IHC model. The results of evaluations indecate that the proposed model is in excellent agreement with the physiological data. To begin an investigation of neural processing beyond the auditory periphery, the model is effective in providing primary inputs to the model of brain-stem nuclei. Additionally, using vowels as input data to the model, we can obtain discharge patterns of all characteristic frequencies (CFs) from the output of the model. These patterns show how the vowel features are represented in the auditory peripheral system.

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