The adaptive neural unit

The neural units in this model are leaky integrate-and-fire neurons with the excitatory neurons having a hyperpolarizing adaptation current. The sub-threshold behavior of the excitatory neural unit is described by:

$$\tau \frac{dV_E(t)}{dt} = -V_E(t) - a(t) + W_{E,E} \cdot i_E(t) - W_{I,E} \cdot i_I(t) + W_a \cdot i_a(t),$$  \hspace{1cm} (1)

The membrane time constant, $\tau$, is 2.75 ms. Entries of connection weight matrices $W_a$, $W_{E,E}$ and $W_{I,E}$ represent thalamocortical, excitatory-excitatory and inhibitory-excitatory connection strengths, respectively. The adaptive current is represented by $a(t)$ and its behaviour is described by:

$$a(t) = \begin{cases} a(t) + a_{inc}, & r(t) > r_{spont} \text{ and } V_E(t) > 0 \\ a(t) - a_{inc}, & a(t) > a_{inc} \text{ and } V_E(t) \leq 0 \text{ and } \alpha \leq 0 \end{cases}$$  \hspace{1cm} (2)

Where $r(t)$ is the neuron’s firing rate, $r_{spont}$ is the spontaneous firing rate, $a_{inc}$ is a constant that is used to increment or decrement the adaptation current, and $\alpha$ is the duration of time after a spike occurs that the neuron cannot recover from its current level of adaptation. $r_{spont} = 8$ spikes/s in silence for neurons in the deafferented region. Finally, $\alpha$, which ensures that the adaptive current recovers minimally during stimulus driven activity, is described by:

$$\alpha = \begin{cases} \alpha - 1, & V_E(t) < 0 \\ T_{rp} + \min(r_{inst}^{-1}, r_{spont}^{-1}), & \text{Upon spiking} \end{cases}$$  \hspace{1cm} (3)

$\alpha$ ensures that the adaptive current will not affect spontaneous firing rates unless a stimulus is first presented. Furthermore, the adaptive current cannot return to baseline while an auditory stimulus is exciting the neuron and causing it to spike. $T_{rp}$ is the refractory period for all neural units, and $r_{inst}$ is a unit’s instantaneous firing rate.
Figure 1: The effect of a 30-second masker stimulus on the firing rate of one of the stimulated neurons in the hearing loss region. The adaptive current causes a gradual drop in the firing rate during the stimulus. After stimulus termination, the hyperpolarized neural unit requires approximately 32 seconds to return to its spontaneous firing rate.