EarLab Simulation Descriptions

Overview

This release of Desktop EarLab comes with a number of preconfigured simulations. These simulations are designed to replicate classic physiological and psychophysical experiments. The purpose of this document is to provide brief descriptions of the experiments. If you are not familiar with the *Experiment Manager* or the *DataViewer*, see the *ReadMe* file under EarLab in the *Programs* section of the *Start* menu.

Normal AN 500 Hz Level Series Experiment

The stimulus in this experiment is a half-second sequence of five 25 ms 500 Hz tone bursts with peak levels increasing in 10 dB steps from 20 dB SPL to 60 dB SPL. To listen to the stimulus, go to the expanded view of the experiment and then open the *Input Directory* folder and double click on *500Hz_level.wav*.

The model consists of modules that simulate the middle-ear, cochlear mechanics, 64 inner hair cells and 64 auditory nerve fibers. The output of the cochlear mechanics module (*NLBM.6.metadata*) is displacement in nm, the output of the inner hair cell module (*IHC.6.metadata*) is receptor potential in mv, and the output of the auditory nerve module (*AN.6.metadata*) is instantaneous firing rate in spikes/second. These files are best viewed with the EarLab DataViewer set to zoom level 4. You can use the *Options* menu or the function keys zoom in (*F1*) and out (*F2*).

Output File: NLBM.6.metadata

Figure 1 shows the output of the non-linear basilar membrane module plotted against best frequency and time with displacement represented using color. The compressive non-linearity present in cochlear mechanics causes an increase in the bandwidth and a decrease in the gain of the basilar membrane frequency response in regions of high response levels. In Figure 1, the stimulus magnitude is increased by a factor of 100 while the BM response only increases by a factor of 16.

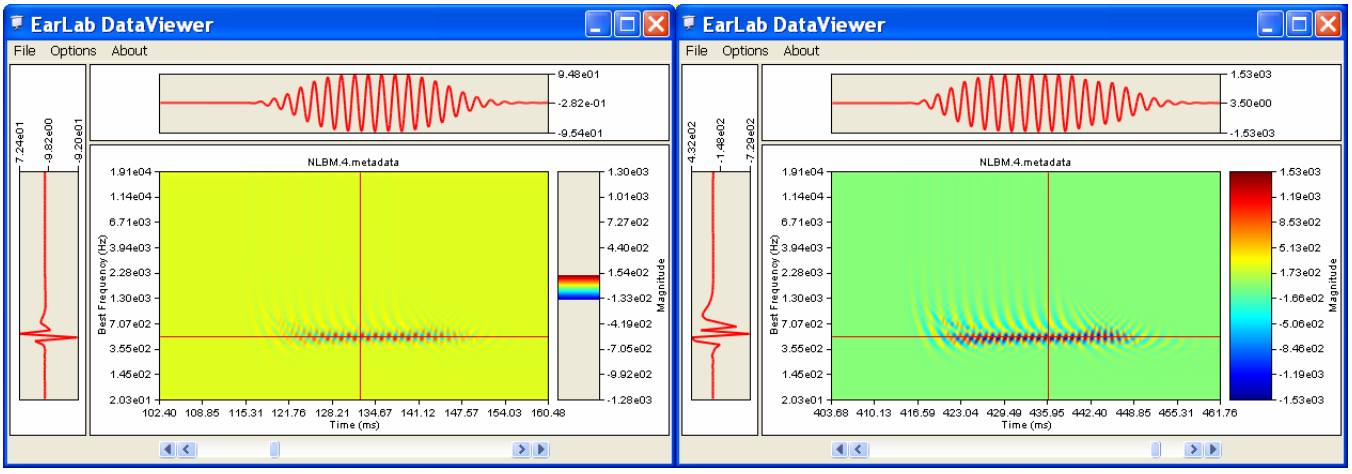

Figure 1. Basilar membrane response to 20 dB SPL (left) and 60 dB SPL (right) 500 Hz tone

Output File: IHC.6.metadata

Figure 2 shows the output of the inner hair cell (IHC) module. The IHC transducer acts as a compressive rectifier and the cell membrane acts as a low-pass filter. IHC activity is plotted against best frequency and time using color to represent change in membrane potential. The dynamic range is compressed such that activity is clearly seen from the lowest to highest stimulus levels. At higher stimulus levels the excitation encompasses a broader frequency range, due to saturation and increasing bandwidth of the basilar membrane filter characteristics.

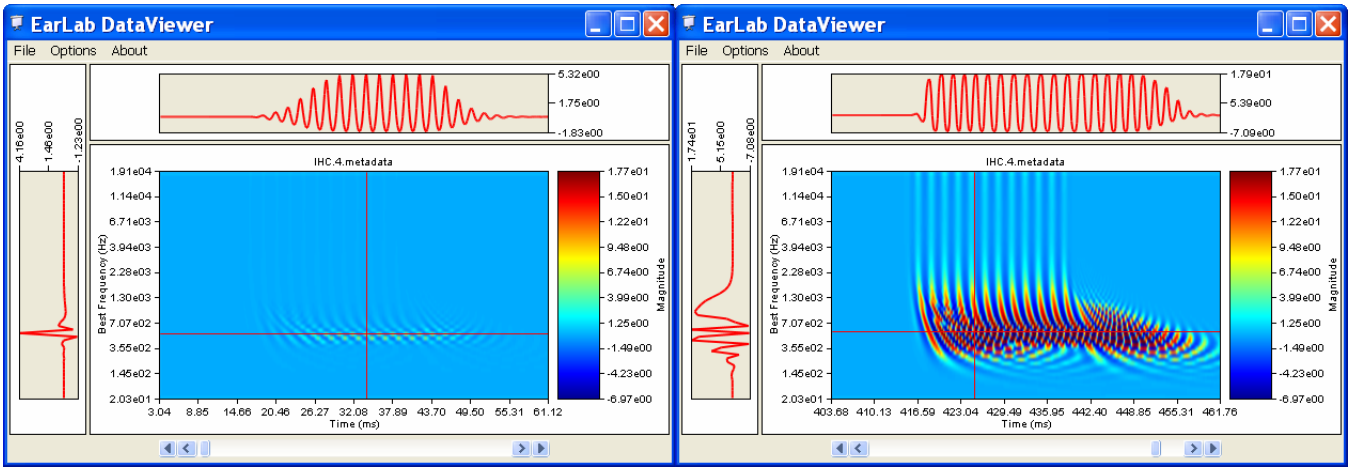

Figure 2. Inner hair cell response to 20 dB SPL (left) and 60 dB SPL (right) 500 Hz tone.

Output File: AN.6.metadata

Figure 3 shows the instantaneous firing rate for the auditory nerve (AN) fiber module plotted against best frequency and time using color to represent firing rate. The module simulates a multi-compartment diffusion model for the IHC-AN synapse. Firing rate varies with the phase of the 500-Hz stimulus, with peak rates at higher stimulus levels being higher at onset and adapting to lower rates during the latter part of the response. At higher stimulus levels the excitation encompasses a broader range of frequency channels around 500 Hz, due to saturation and increasing bandwidth of the basilar membrane's filters.

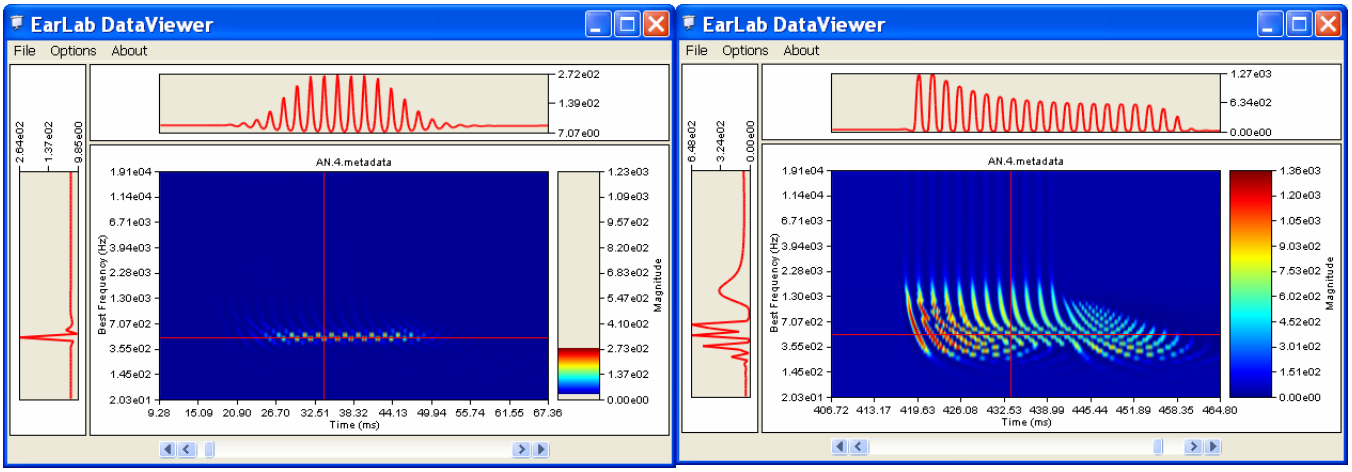

Figure 3. Auditory nerve response to 20 dB (left) and 60 dB (right) 500 Hz tone.

Normal AN 4 kHz Level Series Experiment

This experiment (Figure 4) is similar to the Normal AN 500 Hz Level Series Experiment, except that the stimulus frequency is 4 kHz. At this frequency, the inner hair cell and IHC-AN synapse do not synchronize as well to the stimulus frequency as they did for 500 Hz. The 4 kHz stimulus preferentially excites cells near the base of the cochlea (top of display) while the 500 Hz stimulus excited cells near the apex of the cochlea (bottom of display).

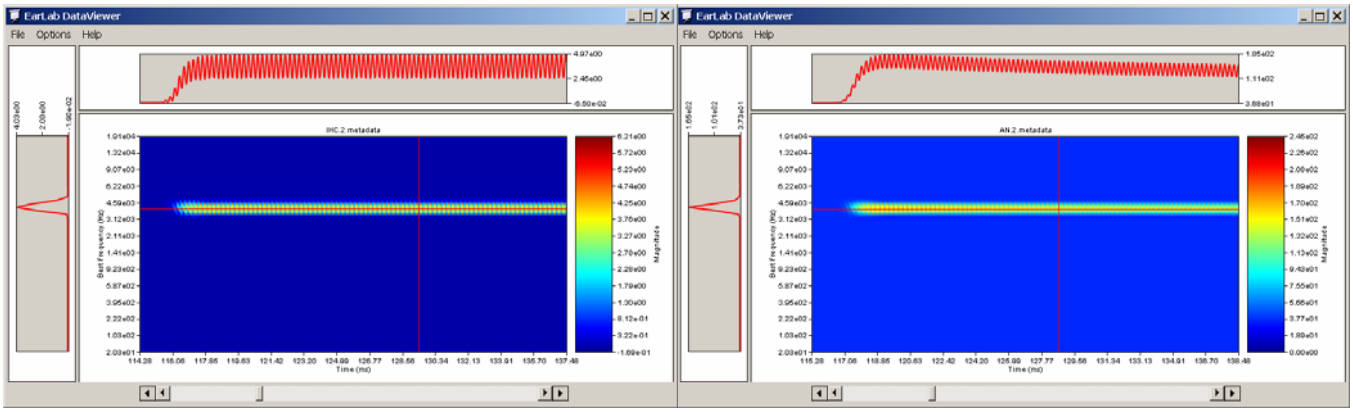

Figure 4. Inner hair cell (left) and auditory nerve (right) response to a 30 dB SPL 4 kHz tone.

Normal AN Frequency Series Experiment

In this experiment, the stimulus is a sequence of 35 ms 40 dB SPL tones with frequencies of 100 Hz, 300 Hz, 1 kHz, 3 kHz, and 10 kHz). This sequence demonstrates the frequency analysis function of the cochlea as well as the progressive transition from following the fine structure of the acoustic stimulus to following the envelope of the stimulus as frequency is increased (Figure 5). Also, one can see that fibers tuned to frequencies other than the stimulus frequency are excited by the tone onset and offset transients. These "off-frequency" responses are due to the basilar membrane ringing at the best frequency for locations near the stimulus best place. This effect is especially noticeable for the 10 kHz stimulus.

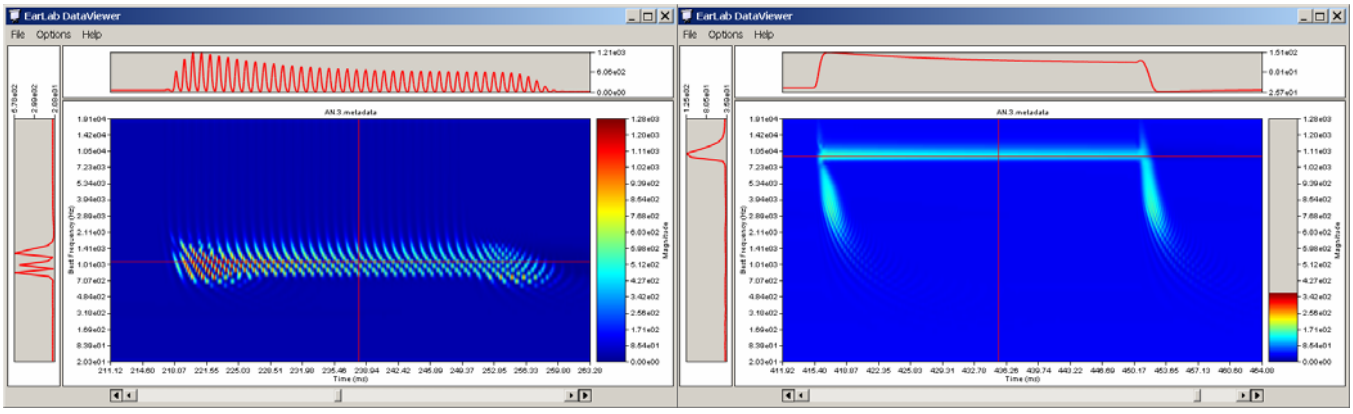

Figure 5. Auditory nerve response to a 1 kHz (left) and 10 kHz (right) tone.

Normal AN Response to Speech and impaired AN Response to Speech Experiments

The normal AN model incorporates the non-linear basilar membrane module (NLBM), while the impaired incorporates a linear basilar membrane (LBM). The NLBM has narrower bandwidth filters at low stimulus levels, while the linear has comparatively wide bandwidth frequency channels at all levels. The overall level of the response for the impaired ear is less than that for the normal ear (Figure 6). Greater frequency resolution in the normal response is illustrated by the presence of formant bands at 2.5 and 3 kHz, and formant shifts in the 500-Hz region (at time 300-400 ms). The vertical stripes with a period of 11 ms correspond to the pitch period of the voiced speech segments. These features are the result of pulses produced by glottis and the formant bands are the result of resonances in the vocal tract.

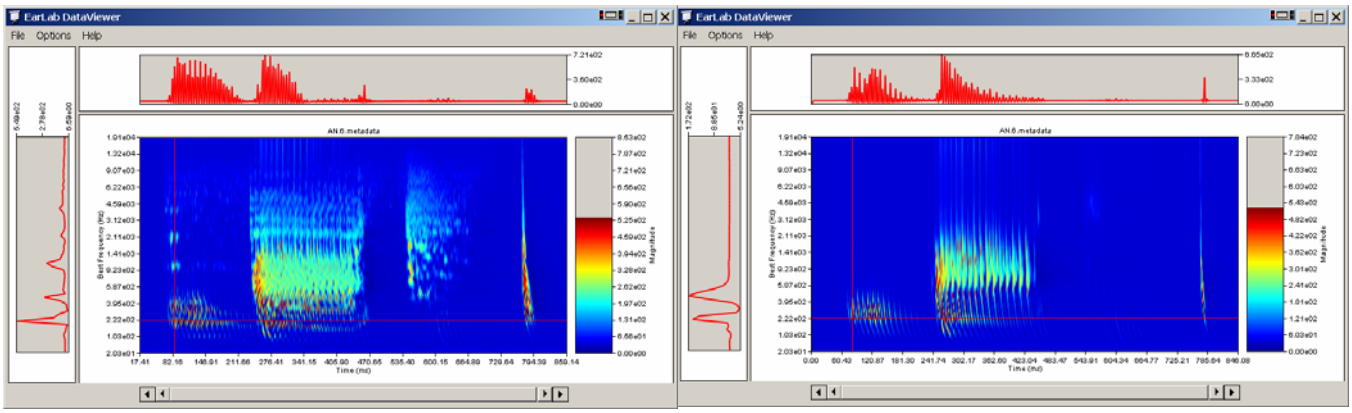

Figure 6. Normal (left panel) and impaired (right panel) auditory nerve responses to speech

AN Forward Masking Experiment 1

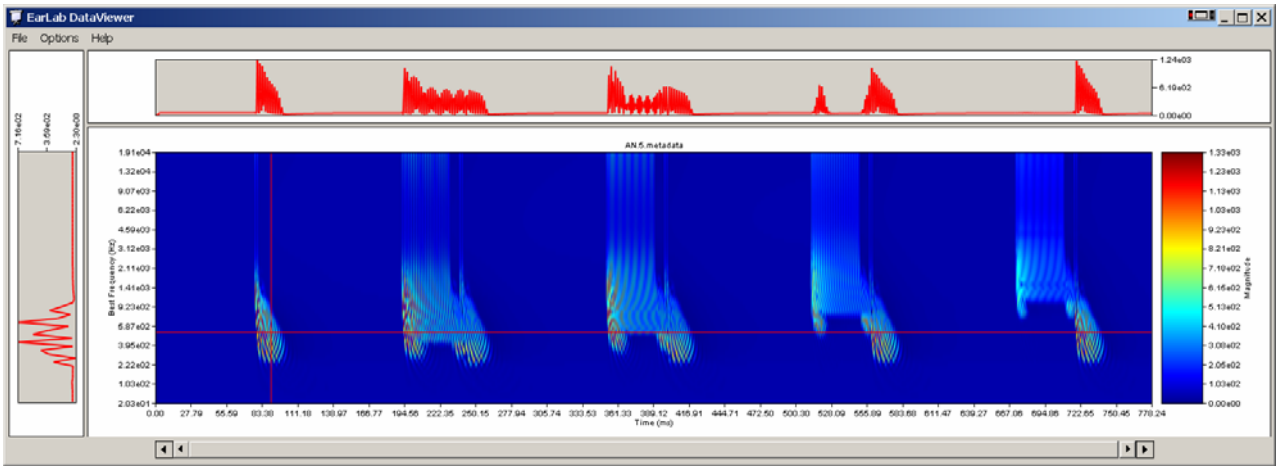

Figure 7. Effect of masker frequency on uditory nerve responses in a forward masking experiment.

Masking refers to the reduction in response to a test signal (target) in the presence of a second signal (masker). If a target signal is closely preceded by a masker with similar frequency content, the response

to the target is diminished. In Figure 7 the response of the normal auditory nerve module is shown for a 500-Hz tone-pip (target), first alone and then proceeded by a tone of longer duration (masker). When the masker frequency is the same as the target frequency, there is a significant reduction in the response to the target. As the frequency of the long-duration tone is increased further above that of the pip with each successive stimulus presentation the reduction in target response decreases. Forward masking in the auditory nerve appears to be due to the same mechanism as the adaptation seen in the response to single tones.

AN Forward Masking Experiment 2

The response of the normal auditory nerve module is shown in Figure 8 for a 500-Hz tone-pip alone and then proceeded by a 500-Hz tone of longer duration. In this experiment the delay between masker and target tone is varied while masker frequency is kept fixed. When the delay is short the after ringing in the tone response overlaps with the onset of the target response. At shorter delays the gap between the tone and pip is obscured and the response to the target stimulus is reduced. Reduction in the target response can be seen even the two responses are well separated in time (4th and 5th responses).

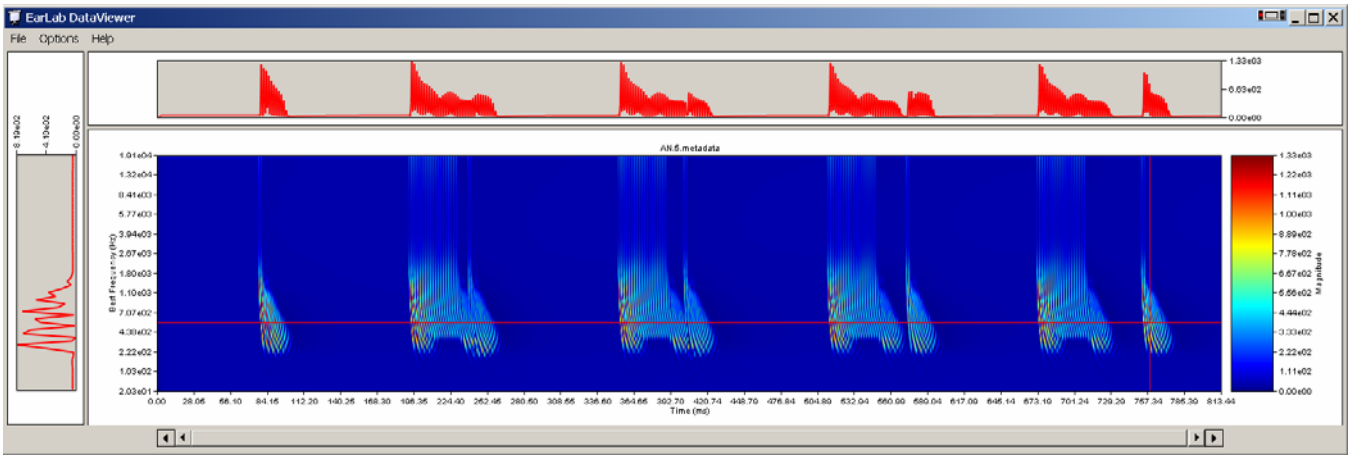

Figure 8. Auditory nerve response in a forward masking experiment where the time delay between masker and target tones is varied.

AN Simultaneous Masking Experiment

AN.6.metadata:

The response of the normal auditory nerve module is shown for two simultaneous tones. 500-Hz tone-pip is preceded by a tone of longer duration. The frequency one tone is increased (from left to right in the figure) as the frequency of the other is held at 500 Hz. The response patterns interfere for small frequency differences, and become more separated for larger differences in frequency.

MSO Binaural Beat Experiment

Differences in intensity and timing at the two ears occur for sound at head level that originate from the right or left of the listener. The medial superior olive (MSO) is one of the first sites in the auditory brainstem to receive inputs from both ears. MSO cells are highly sensitive to the interaural delay of low-frequency sounds. MSO cells are modeled here as cross correlators with an internal time delay. The cross correlators take the instantaneous firing rate of auditory nerve fibers from right and left ears as inputs. The binaural beat stimulus in this experiment is composed of a 1000-Hz tone in the left ear and a

1010-Hz tone in the right ear. The nature of the stimulus is such that the interaural phase will continuously vary between 0 and 2π radians every 100 ms. The DataViewer can be used to view the excitation pattern (Figure 9) for a population of MSO cells over a range of best frequency (y-axis) and best interaural time delay (x-axis). Responses from the right and left MSOs have been combined into a single display to facilitate visualization. Activity in the response pattern occurs for best frequencies around 1000 Hz. The display can be scrolled through successive time steps in the simulation, and as it does, the peaks of activity shift along the interaural time axis. Successive peaks are separated by 1 ms (the period of the stimulus).

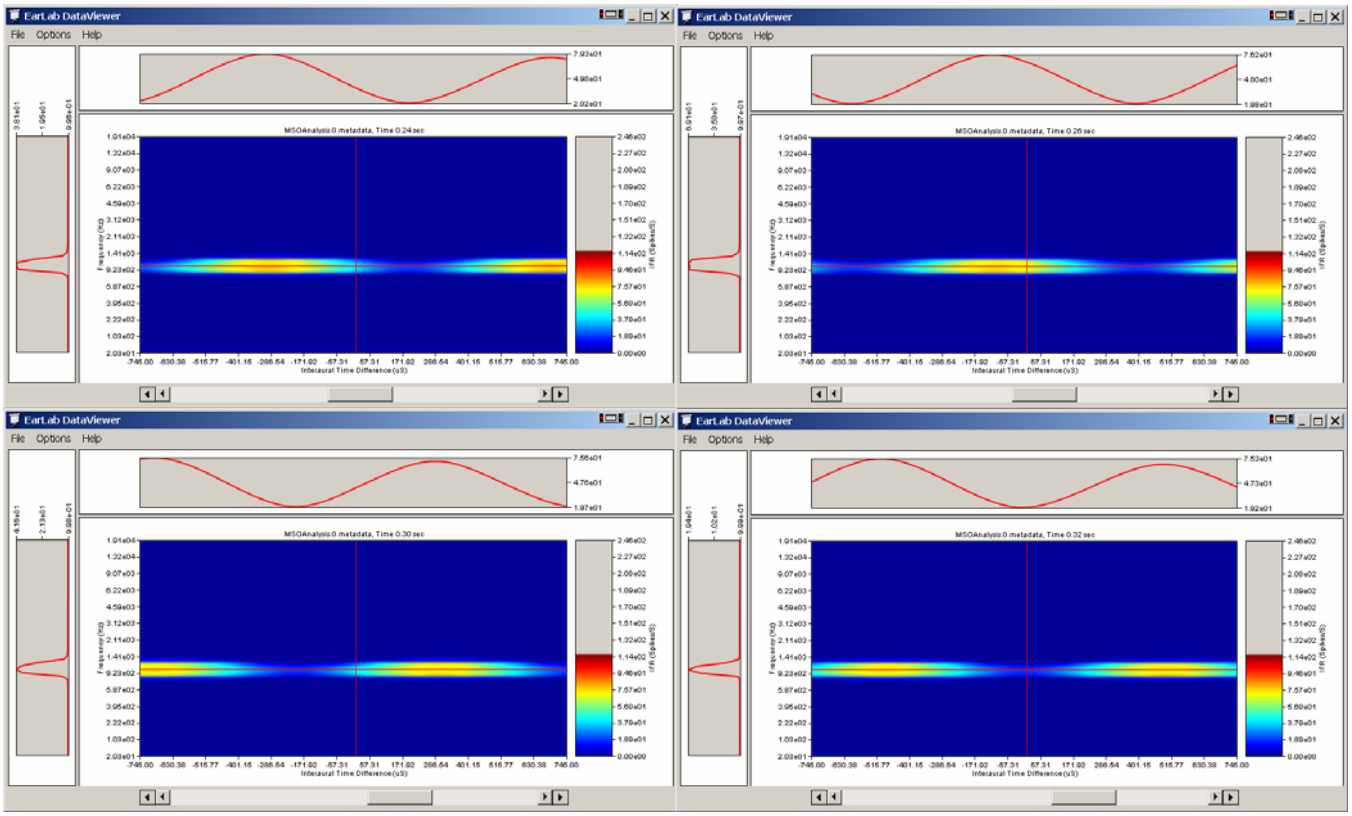

Figure 9. Responses from MSO simulation for a binaural beat stimulus. Successive frames were taken at 20 ms intervals. As time progresses, the pattern moves from left to right.

MSO Level Series Experiment

In this experiment, a 1000-Hz tone with zero interaural delay is applied to the MSO model. As expected, the excitation pattern for the MSO cell population at best frequencies around 1000 Hz and best and interaural time delays around zero. As stimulus level is increased, there is some spread in the excitation pattern along the best frequency axis but the peak in the excitation pattern remains centered over the best delay of zero.

Binaural Release from Masking (MSO tone in noise responses)

If a tone and white noise are added and presented to the two ears in phase (N0S0), the tone is more easily masked by the noise than when the noise is in phase and the tone out of phase at the two ears

(N0Spi). In this experiment, the MSO response to three conditions, N0S0, N0Spi, and noise alone (N0) are simulated. The tone frequency was 1 kHz.
Figure 10 shows the simulated excitation pattern for each stimulus from a population of MSO cells covering a range of best frequencies best interaural time delays. The response to noise alone (N0) shows a strong response at zero delay in the mid frequency region. The lack of delay tuning for higher frequencies is the result of the loss of synchronization to the stimulus fine structure in the auditory nerve. For the N0S0 stimulus, the response is very similar to that for noise alone. When the interaural phase is shifted to pi radians, the response to the noise at zero delay is suppressed in the 1 kHz band and the center of the excitation in this frequency band is shifted to a time delay approximately half way between that expected for the noise (zero) and that expected for the tone (500 microseconds).

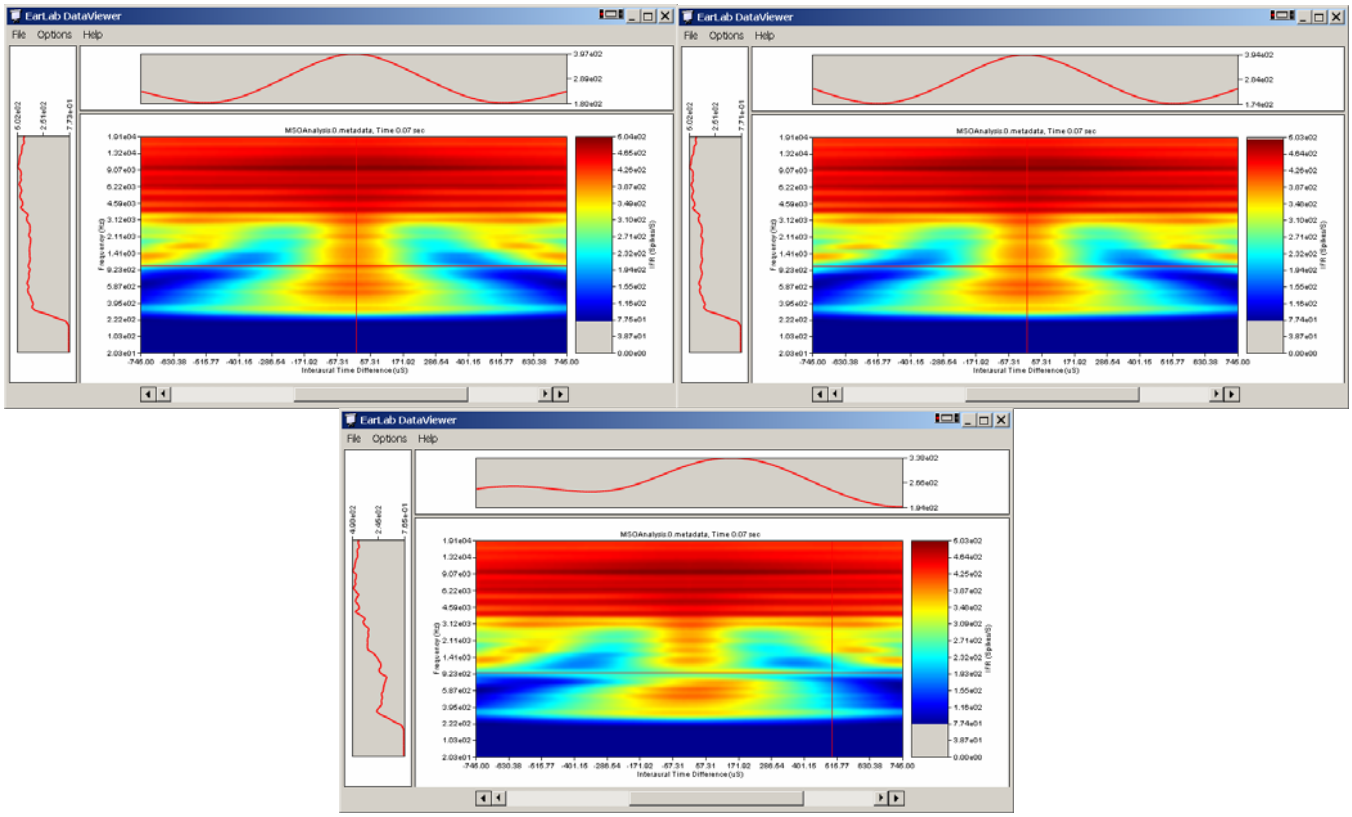

Figure 10. MSO response to white noise alone and tone (1 kHz) in noise. When the noise and the tone are in phase at the two ears, the response to noise alone (upper left panel) and to tone in noise (upper right panel) are indistinguishable. If the noise is in phase while the tone is out of phase(lower panel), then the excitation pattern differs from the noise alone case for best frequencies near 1 kHz.

MSO Precedence Effect Experiment

When two acoustic stimuli with different spatial locations are presented closely spaced in time, the two stimuli are perceived as a single stimulus with a location corresponding to the first stimulus. This effect is referred to as the "precedence effect."

In this experiment, the MSO response is simulated for stimuli like those used in perceptual experiments designed to study the precedence effect. Two clicks (acoustic impulses) are presented, the first with an interaural delay of -350 microseconds, the second with a interaural delay of +350 micro seconds. The

separation between click onsets is varied from 1 ms to 10 ms in 10 steps. When the two clicks are well separated in time, the response to the first click dies out before the response to the second click begins and the excitation patterns for both clicks are centered at the expected interaural delays. When the clicks are presented close together in time, the response to the first click is centered at the proper interaural delay and the response to the second click is masked by the after ringing to the first click.

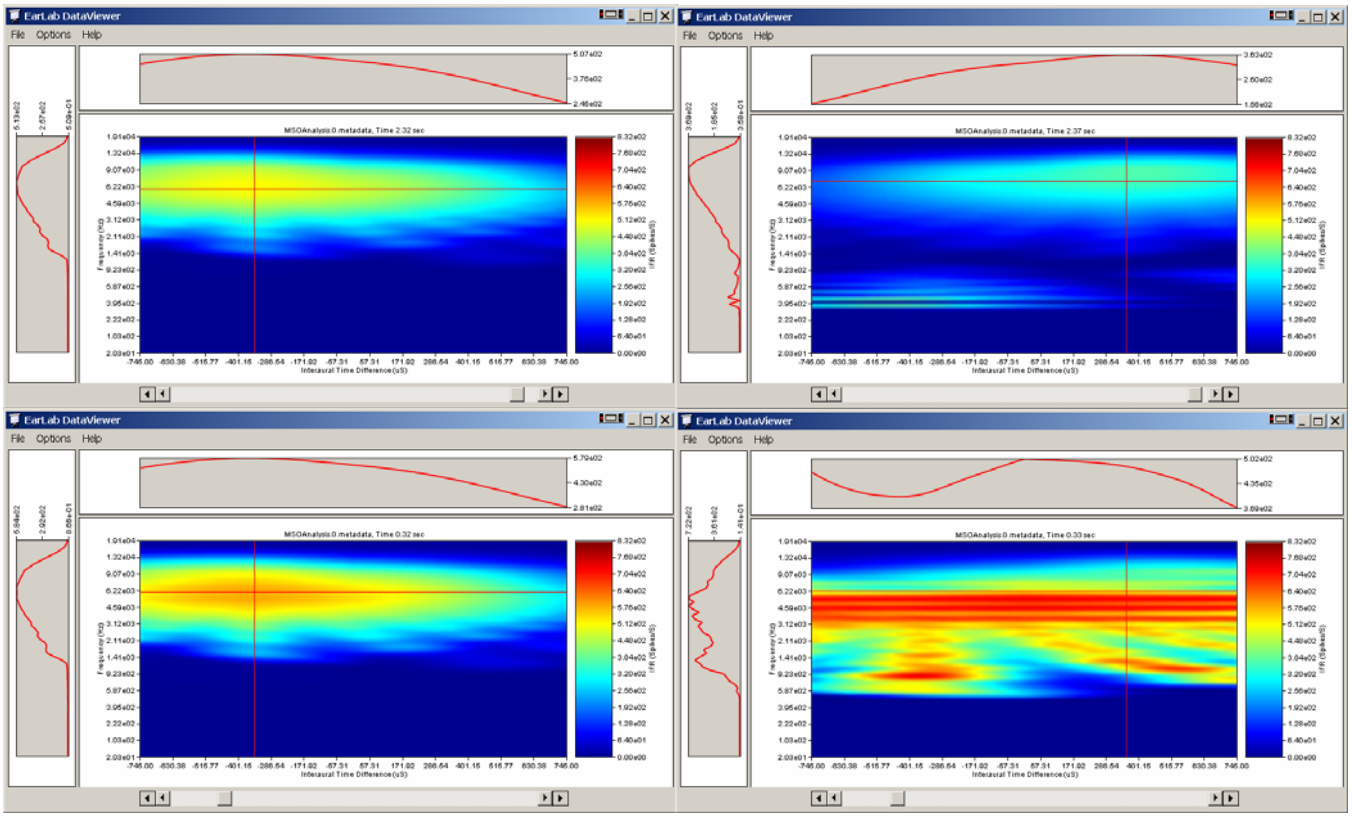

Figure 11. MSO onset responses to pairs of clicks. For the upper panels the delay between click onsets was 10 ms, for the lower row the delay was 2ms. Left panels show the response to the first click, right panels show the response to the second click in the pair. The horizontal position of the cursor is set to the expected interaural time delay.

CN Bushy Cell Tone Response

This experiment is designed to demonstrate modules that generate times of occurrence for action potentials (spikes). The module used stores the output for auditory nerve and cochlear nucleus bushy cell modules. The current version of the EarLab DataViewer does not support spike times but the output files can be viewed with a text editor or by double clicking on the file from within the EarLab Experiment Manager. Also, a MATLAB prototype for spike-time visualization and analysis can be found in the *EarLab* folder under *Programs* in the Windows *Start* menu. Figure 12 illustrates the bushy cell output visualized with the prototype viewer. In the main panel, responses from cells are plotted in order of cell best frequency with low best frequencies the bottom and high best frequencies near the top. Cells tuned to frequencies near 500 Hz show a vigorous response through out the duration of the tone. Cells tuned near but higher in frequency only respond to the stimulus onset. Cells tuned to frequencies far from the stimulus frequency only show random spontaneous firing. The visualizer in Figure 12 is set to display the period histogram (lower left corner) that shows the degree to which the time of occurrence is synchronized to a particular phase of the stimulus period. The synchronization coefficient (sync) is a

measure of this synchronization that ranges from zero for totally random firing to one for the case where every action potential occurs in just one bin of the histogram.

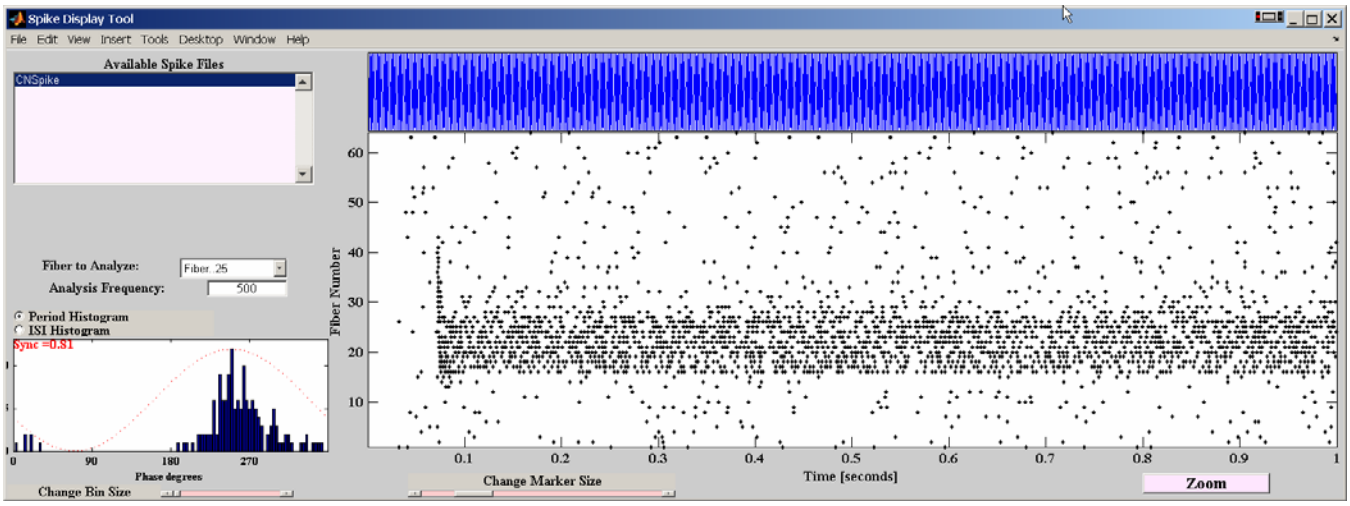

Figure 12. MATLAB prototype for spike-time visualization. The main display panel shows a dot raster display for the response of 64 bushy cells to a 500 Hz tone. The small panel in the lower left is the period histogram for the data from cell number 25. The top panel displays the stimulus waveform. In this example, the stimulus waveform is almost a solid block of color due to aliasing in the graphics.