Sensitivity to ITD changes in a binaural detection model

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Abstract

In this contribution, we analyze the binaural model proposed by Breebaart, van de Par and Kohlrausch in 2001 for its ability to predict just noticeable differences in interaural time differences (ITDs). This model is conceptually similar to crosscorrelation models, and the relevant model property for ITD detection is its internal delay line. We first study which point along the internal delay axis is optimal for detecting a change in the ITD of a sinusoidal stimulus. There are two candidate positions: First, the position where the internal excitation of the reference stimulus has its minimum (e.g., zero ms for a stimulus without any ITD), and secondly a point at which the excitation has its steepest slope. With this analysis, we can also compare the model's thresholds depending on the considered positions. A second question of interest is how the model deals with stimulus randomness in ITD experiments. From perception experiments it is known that the thresholds for sinusoidal stimuli and for narrowband random-noise stimuli with the same center frequency are very close.

Introduction

One of the obvious advantages of having two ears on either side of the head is the introduction of interaural differences in time and intensity for lateral stimuli. Models that predict human sound localization must therefore be sensitive to changes in these parameters. In this contribution, we analyze the binaural detection model proposed by Breebaart et al. [1] for its ability to discriminate stimuli with different values of the Interaural Time Difference (ITD).

A mathematical operation to detect a time delay between two coherent signals is to compute the normalized crosscorrelation function and detect the peak of this function. In binaural models, this operation is often realized by an internal delay line in combination with a coincidence analysis. Changes in ITD are then reflected in changes of the peak position along the internal delay line. Such a scheme gives an intuitive representation of ITD changes, but it does not directly allow to predict threshold sensitivity, unless the amount of internal noise is specified. Bernstein and Trahiotis [2] have prediced ITD thresholds of high-frequency amplitude-modulated sounds from the change in the normalized correlation at internal delay zero. Colburn et al. [3] have analyzed the information available for detecting changes in ITD along the internal delay line. They showed that the "best place" to look for a change in interaural delay it not at τ=0, but at a place where the excitation of the reference stimulus

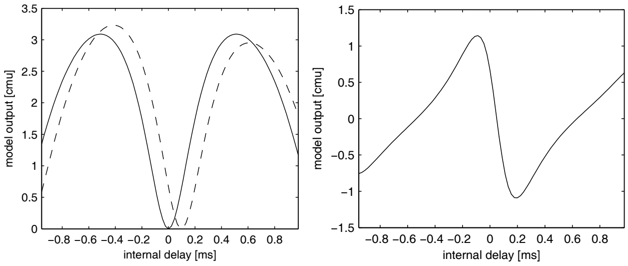

Figure 1: The left panel shows excitation (in model units) along the internal delay line for a stimulus with 0-ms (solid line) and one with 0.1-ms interaural delay (dashed line). The right panel shows the difference between the two excitations.

changes most strongly. For the crosscorrelation function of a sinusoidal stimulus, the "best delay" would occur at an interaural delay corresponding to a phase shift $\pi/2$.

In this contribution, we will analyze interaural delay detection in the model by Breebaart et al. Two questions will be addressed: How different are the threshold predictions, if the detector analyzes only the delay 0 ms or the "best delay"? Are there differences in ITD threshold predictions for deterministic (sinusoidal) and nondeterministic stimuli (random noise)?

Model analysis

The relevant model component for our analysis is the binaural display which has the axes internal interaural delay and internal interaural attenuation. Only the first axis will be considered in the following. Because the central processor is based on an excitatory-inhibitory (EI) interaction between signals from the right and left ear, the place along the internal delay axis that matches the external interaural delay of a dichotic stimulus is characterized by *minimal* activity. This is shown in the left panel of Fig. 1, where the continuous line shows the internal activity for a stimulus with no external delay, and the dashed line show the same stimulus with a 0.1-ms external delay: The minima of the two patterns are shifted along the internal delay axis. The right panel shows the difference between these patterns. The (absolute) difference is largest at two places which are clearly different from 0. We can therefore expect that our model will predict different thresholds, depending on the internal delay used in the detection process. This is confirmed by the data in Fig. 2, where we show threshold ITD values for sinusoids of different frequencies, for three different model versions: Detection based on the difference in internal excitation at delay 0 ms (triangles); detection based on the position with a maximum of the the dif-

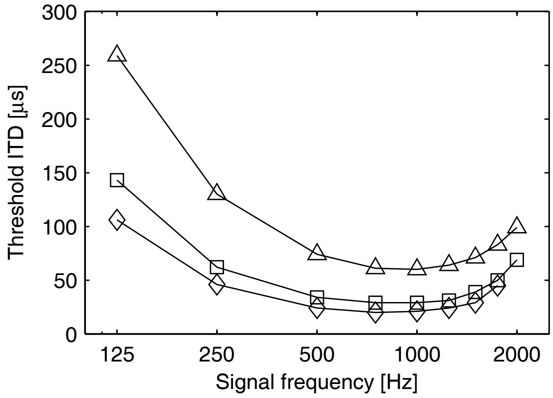

Figure 2: ITD thresholds for sinuoids with different frequencies computed with three model versions: Analyzing internal delay 0 ms (triangles); analyzing the best delay (squares); analyzing the two best delays (diamonds).

ference pattern (squares); detection based on an optimal combination of the two best positions (diamonds). The amount of internal noise was constant at each internal delay element.

These simulations support the analysis performed by Colburn et al. that detection of a change in interaural delay is best done at an optimal place away from 0 ms. Actually, the best performance would be reached if the difference pattern was analyzed across all possible delays, with a weighting given by the difference function in the right panel of Fig. 1. Although such a computation is, for complexity reasons, not possible, one can predict that threshold would be much lower than psychophysically observed, unless the amount of internal noise in the model was set to a higher level.

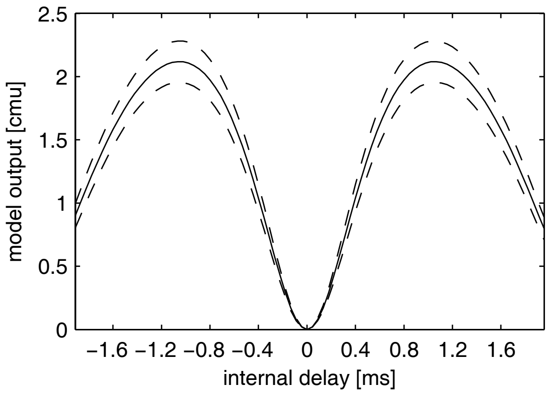

Figure 3: Mean and standard deviation of the internal excitation computed for 50 realizations of random noises with a bandwidth of 115 Hz and no interaural delay.

In the following, we want to analyze the ITD sensitivity for a nondeterministic signal, for which the internal representation is influenced by external stimulus variability. We first computed the mean and standard deviation of the internal representation based on 50 independent noise samples with a bandwidth of 115 Hz, 400-ms duration and no interaural delay. Figure 3 shows that, at the

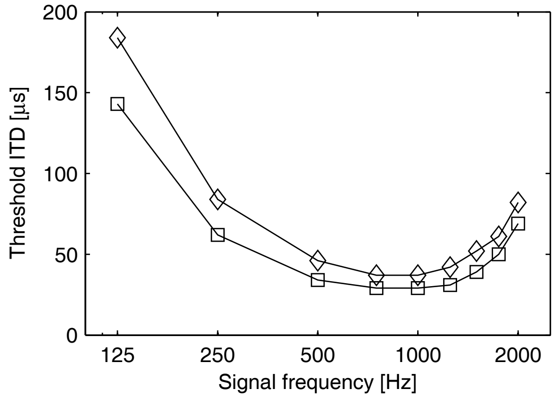

Figure 4: Model predictions for ITD threshold for sinusoids (squares) and 10-Hz-wide random noise signals (diamonds) as a function of frequency.

minimum of activity, the pattern always reaches 0 and is not influenced by external variability. The variability increases with increasing mean activity. A comparison of this external variability with the amount of internal noise that is added in the detection process reveals that the internal noise has a much higher value. Thus, the external variability will have a negligible contribution to ITD detectability and we expect that ITD detection for random signals leads to approximately the same thresholds as for sinusoidal signals. Such simulated threshold values are shown in Fig. 4 for sinusoidal signals (squares) and narrowband-noise signals (10-Hz bandwidth, diamonds) and indeed, they are quite similar. The remaining difference seems to be rather a consequence of slight differences in the peripheral (monaural) parts of the model. This result from simulations agrees with own experimental data (not shown) which reveal overall no significant differences in ITD thresholds for deterministic and nondeterministic signals.

In summary we have shown that also in a computational binaural model, detection of ITDs is best performed at an internal delay different from 0, and that stimulus variability does not influence ITD sensitivity for long-duration signals at low frequencies.

References

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