Modeling the Precedence Effect for Noise Bursts of Different Durations

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Abstract

Recently, a number of binaural models have been applied to explain the precedence effect for experiments using click pairs without the need of contralateral-inhibition elements as proposed by Lindemann in 1986. These findings raised the question of to what extent those types of models were able to explain experiments for lead-lag pairs with longer durations. The simulation revealed that models which simulate the precedence effect by using the special characteristics of the auditory periphery or by focusing on the spectral-dominance region fail when stimuli of longer duration than clicks are used, while a modified Lindemann model still shows satisfactory results. In order to simulate the data for the ongoing (nonimpulsive) stimuli, the degree of inhibition, which was originally adjusted to simulate the precedence effect for click pairs, had to be increased considerably. However, with increasing the parameters for inhibition, the model performance degrades when analyzing click pairs. These findings indicate that the degree of inhibition increases dynamically with the exposure time of the stimulus.

Introduction

Recently, it was shown that the Lindemann model can be extended to simulate psychoacoustical data for signals of longer duration (noise-bursts of different bandwidths 100 Hz, 400 Hz and 800 Hz) than clicks [2]. The psychoacoustical reference data—in which the perceived lateral position of a noise burst (200-ms duration, 20-ms $\cos^2$-ramps, 500-Hz center frequency) in presence of one reflection (inter-stimulus interval: 0.0 ms–0.4 ms) was determined—were taken from a preceding paper on this investigation [1]. In order to simulate the data, the original model of Lindemann [4] had to be modified in two ways: (i) the degree of inhibition had to be increased and (ii) the signals had to be compressed beforehand. By implementing the latter, the model simulation could be ran independently for interaural time difference and interaural level difference cues. In the a following investigation reported here, the performance of the modified model was tested for data on click pairs. As a reference, an experiment from the classical paper of Wallach *et al.* [7] was chosen. It was especially of interest to us whether the same set of model parameters can be used as for the ongoing stimuli, or whether the parameters have to be re-adjusted in this task.

The Experiments of Wallach *et al.*

Wallach *et al.* [7] investigated in one of their psychoacoustical experiments using click pairs how the ITD of the lead influences the perceived lateralization of the click pair. In their experiments, the clicks had a duration of 1 ms. The ITD of the lag was either adjusted to $\pm 400\,\mu$s or $\pm 600\,\mu$s. The ITD of the lead was varied pseudo-randomly between values from $-100\,\mu$s to $100\,\mu$s in steps of $10\,\mu$s. In the original experiment, every condition was repeated 20 times, and the task of the two listeners was to judge whether they perceived the auditory event on the left or right side. (In our model simulation, we measured the estimated lateral position of the click pair instead.) The classical results of Wallach *et al.* [7] first showed that a relatively small ITD ($|20|$ – $|50|\,\mu$s) of the lead compensates for the larger ITD of the lag (judgements 'right'=50%), the phenomenon which is now termed as *"localization dominance."*

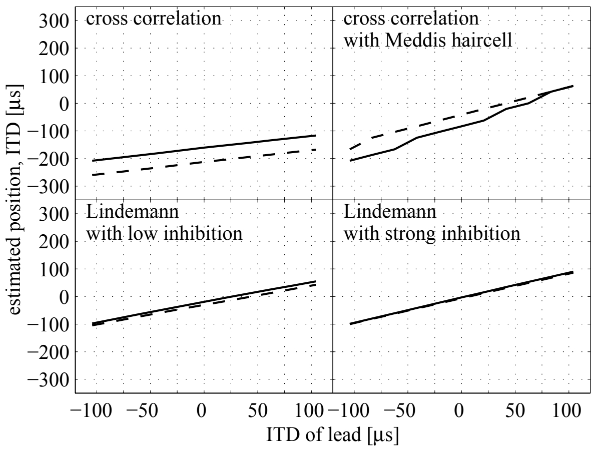

Figure 1: Simulation of Wallach *et al.*'s psychoacoustical results with different implementations of the cross-correlation model: plain cross-correlation model (top-left panel), cross-correlation model with Meddis hair-cell model (top-right panel), Lindemann model with weak inhibition (bottom-left panel, c_s=0.5, c_d=0.5, T_{inh}=10 ms) and Lindemann model with stronger inhibition (bottom-right panel, c_s=0.9, c_d=0.5, T_{inh}=50 ms). The solid lines show the conditions in which the ITD of the lag click is set at $-400\,\mu$s, the dashed lines depict those conditions in which the ITD of the lag click is set at $-600\,\mu$s.

Simulation results

The simulation results for Wallach *et al.*'s experiment [7] are shown in Figure 1. The architecture and parameter settings of the models used here are identical to those described in [2], except for the variation of the inhibition parameters c_s and T_{inh} as described further below. The top-left panel of Figure 1 shows the results for the basic cross-correlation model without any inhibitory elements.

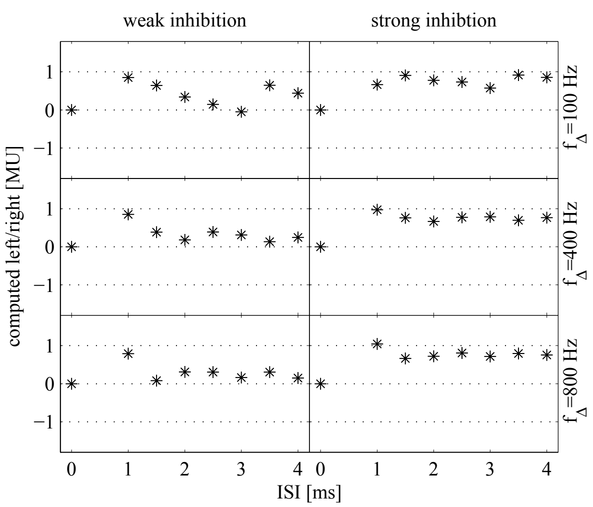

Figure 2: Model performance of the cross-correlation model with inhibition stage for the lateralization of a noise burst in the presence of a reflection for different ISIs and bandwidths (from top to bottom row): 100 Hz, 400 Hz, 800 Hz. In the left panels, the results for the cross-correlation model with weak inhibition (c_s=0.5, c_d=0.5, T_{inh}=10 ms) are shown. The results for the model performance with strong inhibition is depicted in the second column from the left (c_s=0.9, c_d=0.5, T_{inh}=50 ms).

The results differ from those of Wallach *et al.*'s experiments: (i) the estimated position of the auditory event is, for the tested ITDs, never at the center (0-μs ITD), and (ii) the estimated position is always larger when the lead is set at -600-μs ITD compared to the condition in which the lead is adjusted to -400-μs ITD. In most situations in Wallach *et al.*'s experiment, the compensating ITD of the lead was slightly lower when the lag ITD was set to -600μs compared to the -400-μs condition. The analysis of the ILDs using the EI model, which is described throughout [2], revealed that the resulting ILD taken as an average over all frequency bands is less than 1 dB and is therefore negligible. With the Meddis-hair cell model [5] being included in the cross-correlation algorithm (top-right panel), the simulation data were in full agreement with the psychoacoustical results of Wallach *et al.* [7], as was already pointed out by Hartung and Trahiotis [3]. The estimated position of the auditory event is at the center when the lead is adjusted to approximately 50 μs. This value decreases when the ITD of the lag is decreased from $-400\,\mu$s to $-600\,\mu$s.

The bottom-right panel of Figure 1 depicts the results for the modified Lindemann model. Principally, the results of the model simulations agree well with the psychoacoustical experiments, with the exception that the localization dominance is found to be slightly stronger than it was found in the psychoacoustical investigation of Wallach *et al.* [7]. The ITD of the lead compensates the opposing ITD of the lag at smaller values ($\approx 5\,\mu$s instead of $|20-50|\,\mu$s) as found in Wallach *et al.*'s listening test. This problem can be solved by reducing the inhibition constants (c_s and T_{inh}) to a values of 0.5 and 10 ms (bottom-left panel). However, when simulating the psychoacoustical data for ongoing band-pass-filtered noise bursts, the model is no longer able to simulate the effect of localization dominance when the degree of inhibition is set too small (Figure 2).

Conclusion

Already Lindemann adjusted the inhibition factors to different values (0.3 or 0.5) depending on whether he analyzed bandpass-filtered clicks or continuous sinusoidal sounds. Regarding the signal-dependent component adjusting the inhibition factors, one also has to consider the build-up effect of the precedence effect. The existence of this effect implies for our understanding of the precedence effect that the inhibition increases with the duration of the signal, and the parameters related to inhibition, c_s, c_d, and T_{inh}, that were proposed by Lindemann [4] as constants, are probably dynamic parameters which increase with the time of exposure to a signal. Another solution would be to implement a second onset-triggered inhibition unit with a longer time constant on top of the Lindemann model, as was done by Djelani [6] to simulate the build-up effect of the precedence effect for click trains.

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References

[1] J. Braasch, J. Blauert, T. Djelani. "The precedence effect for noise bursts of different bandwidths. I. Psychoacoustical data," Acoust. Sci. & Tech., 24 (5), 233–241 (2003).

[2] J. Braasch, J. Blauert. "The precedence effect for noise bursts of different bandwidths. II. Comparison of model algorithms," Acoust. Sci. & Tech., 24 (5), 293–303 (2003).

[3] K. Hartung and C. Trahiotis, "Peripheral auditory processing and investigations of the "precedence effect" which utilize successive transient stimuli", J. Acoust. Soc. Am. **110**, 1505–1513 (2001).

[4] W. Lindemann, "Extension of a binaural cross-correlation model by contralateral inhibition," J. Acoust. Soc. Am. **80**, 1608–1630 (1986).

[5] R. Meddis, M. J. Hewitt and T. M. Shakleton, "Implementation details of a computational model of the inner hair-cell auditory-nerve synapse," J. Acoust. Soc. Am. **87**, 1813–1816 (1990).

[6] T. Djelani, "Psychoakustische Untersuchungen und Modellierungsansätze zur Aufbauphase des auditiven Präzedenzeffektes," Dissertation Ruhr-Universität Bochum (2001).

[7] H. Wallach, E. B. Newman and M. R. Rosenzweig, "The precedence effect in sound localization," Amer. J. Psychol. **57**, 315–336 (1949).