# Differential contribution of interaural time and level differences to the precedence effect at high frequencies

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## Summary and Introduction

The precedence effect (PE) allows us to locate sound sources correctly in rooms despite the presence of interfering reflections. It was shown to function at high frequencies with highly modulated stimuli even when lead and lag had simultaneous onsets, i.e. with information restricted to the ongoing sound part [1]. These studies were done in the free-field where interaural time (ITDs) and level (ILDs) differences are in their natural combination. The present study investigated the relative contribution of ILDs and ITDs to the PE and if either cue alone is sufficient to evoke the PE. Zero-phase harmonic complex tones restricted to high-frequencies were used. At high frequencies only ILDs and ITDs carried in the envelope are used by the binaural system and it is questionable if they can be accessed in the presence of a sound reflection.

A lateralization dominance task was used where participants indicated the location of the lead-lag stimuli and rated if sounds were perceived as fused. Results show that the PE emerges with ITDs applied to lead and lag while ILDs were kept at zero and, vice versa, with ILDs applied and ITDs kept at zero. Patterns for localization dominance and fusion were nearly identical for ITD and ILD conditions, suggesting that each cue has similar potential to evoke the PE. However, lateralization was stronger when both ITDs and ILDs were applied to the stimuli. At long delays, an image was reported at the lead location only for larger binaural cues; otherwise the image was centred. Echo thresholds were generally short in all conditions (3-4 ms) and independent of the binaural cue (ITD or ILD) and its magnitude. The high similarity between the results for ITDs and ILDs supports the idea that the PE shares the same mechanism for ITDs and ILDs.

## Methods

Lateralization dominance was studied with stimuli consisting of a leading and a lagging sound which were presented via headphones and lateralized by applying a full-waveform ITD or an ILD, or both. In half of the trials, the lead had binaural cues indicating a source on the right (positive-valued ITDs or/and ILDs), while the lag, which was an identical, delayed copy of the lead, carried binaural cues of the same magnitude, but indicating a source on the left (negative-valued ITDs/ILDs). In the other half of the trials the sign of the binaural cues in lead and lag was inverted. After the lead-lag stimulus was played, listeners indicated its intracranial location using line dissection method. A line was presented on a computer screen with the endpoints labelled "left ear" and "right ear". Listeners were instructed to place a movable vertical bar such that it dissects the line according to the lateralized position. If subjects perceived separate images for lead and lag they were instructed to indicate the leftmost image. Randomizing the side of lead and lag thus meant that subjects indicated the lead in one half of the trials.

Localization results were collected for lead-lag delays of 0, 1, 2, 3, 4, 5, and 7 ms. ITDs of 0, 0.3 and 0.7 μs were applied to the stimuli and paired in any possible combination with ILDs of 0, 4 and 9 dB.

The sound pressure level of lead and lag was 55 dB SPL. Six trials were collected for each ITD (3), ILD (3), delay (7) and lead direction (2), giving a total of 756 trials per participant. Trials were administered in random order and the presentation was divided into 8 runs of about 8 min each. Brief training was given prior to data collection.

The stimulus was a harmonic complex tone with a fundamental frequency of 50 Hz. Each harmonic had zero starting phase, yielding a highly modulated, "peaky" stimulus. Lead and lag were simultaneously gated with a slow, 50 ms rise time to minimize the dominance of the initial onset. The duration of the stimulus was 500 ms and it was bandlimited to 2.0-8.0 kHz. At those frequencies interaural time differences cannot be extracted from the temporal fine structure of the sound and the auditory system relies on ITDs carried in the sound's envelope. The question was if the PE can be evoked by either ITDs or ILDs alone when those cues are accessible exclusively from the sound's envelope.

Seven normal hearing listeners (<20 dB HL) participated, though only the results of one are presented. Subjects were paid and the study was approved by an ethics committee.

## Results and Discussion

Results of the lateralization dominance test for the different ITD and ILD conditions are reported in Figure 1. The PE was active already for the smallest ITD of 300 μs or ILD (3 dB) in the test as demonstrated by the shift of median responses toward the lead. Larger ITDs or ILDs caused images to be lateralized further toward the ears. Echo thresholds (ETs), the delay at which responses for the lead on the right crossed to the left (the instruction was to point to the left image, the lag) were 3 to 4 ms. ETs were almost independent of the magnitude of the binaural cues. However, localization of the lead image at delays larger than the ET was impaired in conditions with small binaural cues and an image in the middle between lead and lag was localized. Only with ITDs of 700 μs or ILDs of 9 dB was the lead localized at a position toward the left ear.
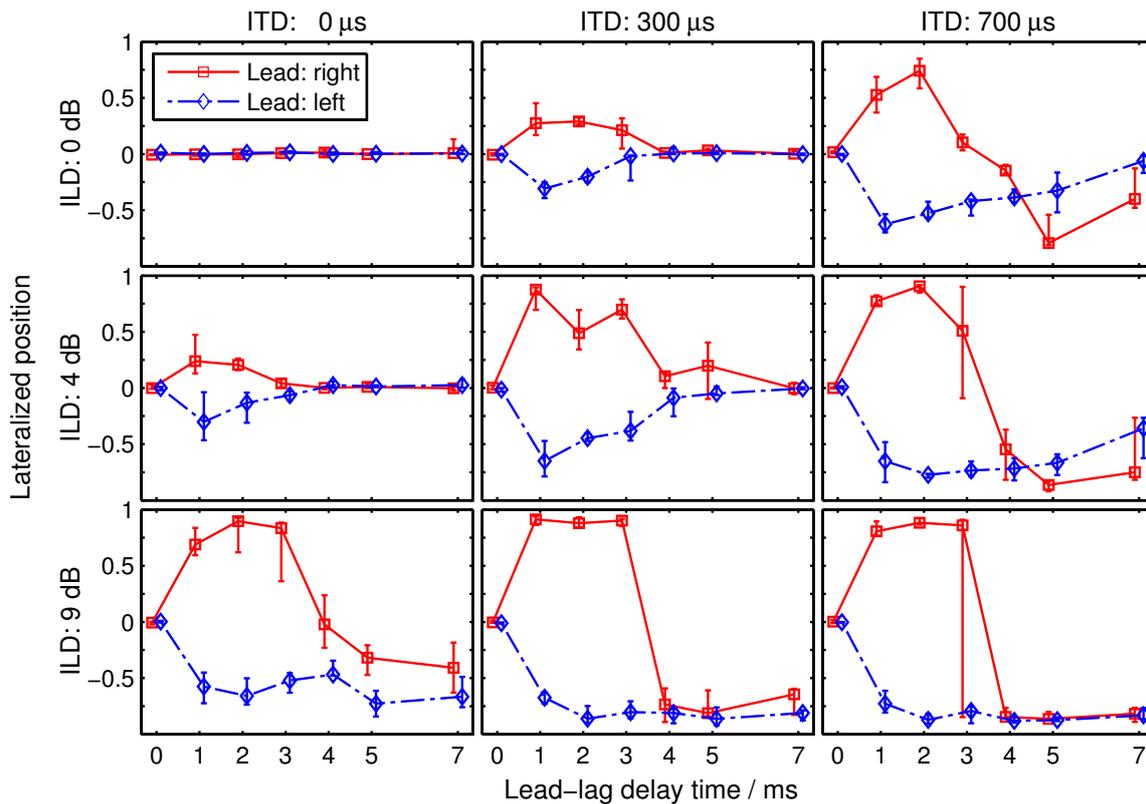
**Figure 1: Lateralization results of one subject for lead-lag stimuli as a function of delay time. Columns represent conditions with different ITDs, rows with ILDs. Data are given as medians, connected by lines, and quartiles. Squares indicate conditions when the lead was on the right and diamonds conditions with the lead on the left. Note that the instruction was to indicate the left image when two images were heard; hence responses shift to the left above the echo threshold.**
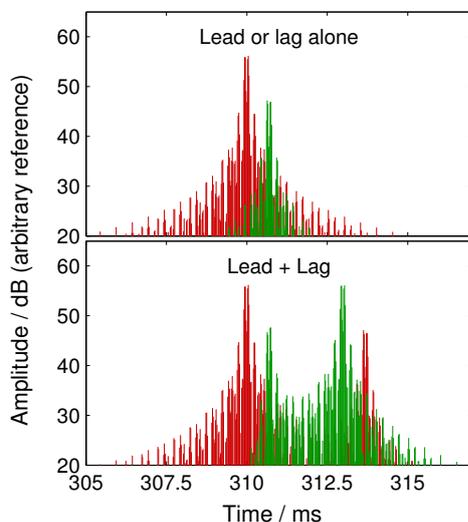


**Figure 2: Amplitude values as a function of time of the lead stimulus (top) and of the combined lead-lag stimulus (bottom). Red values present the right channel and green values the left. Note that the sum of lead and lag carries an average ILD of zero because of the symmetry of the binaural cues in lead and lag.**

The PE emerged when an ITD or an ILD was applied to lead and lag while the other binaural cue was kept at zero. This is particularly interesting for ILDs. Figure 2 shows the lead alone (top) as well as the combined lead-lag stimulus using a fine temporal scale. The ITDs and ILDs carried in the lead clearly visible. Likewise, the bottom panel shows the left-right symmetry between lead and lag. Although the ILD is inverted in the lag, there is no overall ILD in the stimulus that could explain its lateralization toward the lead side. In other words, in conditions where lateralization dominance was observed for ILDs only (see Figure 1), lead-lag stimuli did not have an overall ILD, nor an ITD. Thus, the auditory system must have been able to access the ILD of the lead stimulus despite the quick succession of the lag. This requires a high temporal resolution for ILDs of at most a few ms. However, accurately computing an ILD requires temporal integration over several neural pulses, a process that would limit temporal resolution.

The fact that the time course and the lateral extent of lateralization dominance are highly similar for ITDs and ILDs suggests that ITDs and ILDs share a common mechanism. The results extend previous observations by Zurek for a single broadband click and show that echo thresholds are identical for the PE with ITDs and ITDs when stimuli are restricted to high frequencies, i.e. when access to cues in the temporal fine structure is limited [2].

## Acknowledgements

## References

[1] Seeber, Fortschritte der Akustik – DAGA'11, pg. 833f.

[2] Zurek, J. Acoust. Soc. Am. 67(3): 952-964, 1980.