Localisation dominance for long lead-lag stimuli in background noise

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Introduction

To our knowledge there are only few free-field studies [2,3, 7] examining the precedence effect in background noise. All these studies have in common that they either used short lead-lag stimuli or that background noises were presented from front or back directions, leading to strongly correlated signals at the listener's ears. Neither of both mimic realistic sensations: Common acoustic signals are longer than clicks, and listening in reverberant rooms leads to decorrelated sounds at the ears, especially for sources off the median plain. Therefore, this study investigates localisation of longer duration lead-lag stimuli in background noise that is decorrelated between the ears.

Additionally, we want to examine the influence of coherent amplitude modulation of lead and lag on their fusion. Seeber (2008) [5] was able to show that coherent amplitude modulation leads to increased echo thresholds in quiet, but the effect with background noise remains unknown. Using our "Simulated Open Field Environment" and a method introduced by Seeber and Hafter (2006) [6] we studied localisation dominance, and, at the same time, echo thresholds for the aforementioned conditions.

Methods

Subjects

Four normal hearing participants, aged 22 to 31 years, took part in our experiments, one of them being the first author. None of the participants reported any hearing problems.

Setup

Experiments took place using the Simulated Open Field Environment located in an anechoic chamber. Subjects were looking to the front with their head supported by a headrest, facing a projection screen at a distance of 1.05 meters. Two loudspeakers at ±30º were used to present the target stimuli. These consisted of a single sound (called the lead) from one of these speakers followed by its copy, the lag, from the other. Additionally, four speakers at ±50º and ±130º emitted uncorrelated noise during trials where lead and lag had to be localised in background noise.

Stimuli

Target lead-lag stimuli were localised in quiet as well as in simultaneous background noise. The time-course of lead-lag stimuli is given in Figure 1.

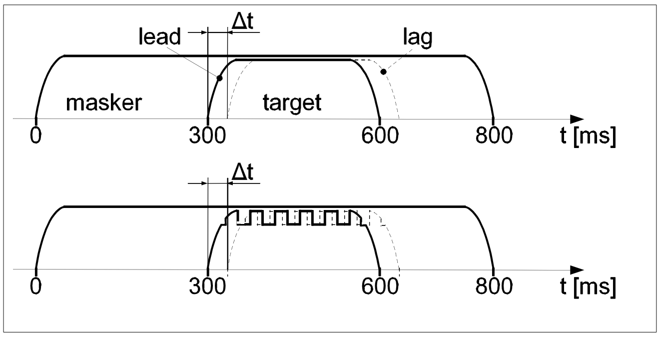

Figure 1: Time course of the noise and the target lead-lag stimuli for the unmodulated (top) and modulated (bottom) condition.

Target stimuli: Target stimuli were composed of Gaussian white noise bandlimited to 300-2000 Hz with a duration of 300 ms. Stimuli were generated in the frequency domain with unity magnitude and random phase in the passband and a level of 60 dB SPL. The resulting signals were either amplitude modulated with the maxima kept constant („modulated condition") or unmodulated („unmodulated condition"). Amplitude-modulation was done using a rectangular envelope starting in the minimum with a modulation-frequency of 30 Hz and a modulation-degree of 50 % (modulation-depth of 9.54 dB). Modulated stimuli were again bandlimited to their initial bandwidth to eliminate spectral splatter. For both conditions on- and offsets were Gaussian shaped with risetimes of 50 ms to minimize onset cues (Rakerd and Hartmann, 1986, [4]). Stimuli were genereted anew in every trial. Identical copies were played as lead and lag from the respective speakers seperated by nine time delays Δt ranging from 0 to 19 ms.

Background noise stimuli: As for the target stimuli background noise stimuli were also bandlimited white noise samples generated in the frequency domain. Bandwidth was 200-6000 Hz, duration was 800 ms and on- and offsets were Gaussian shaped with risetimes of 50 ms. The spectral density levels of the background noises were set to give a signal-to-noise ratios (SNRs) of +10, +5 and 0 dB at the center of a listeners head when played back simultaneously with the target stimuli. A SNR of 0 dB means that target and background noise stimuli had equal spectral density levels. The four different speakers played uncorrelated noise to make a diffuse background noise.Simulations of that noise using KEMAR HRTFs showed an interaural coherence of approximately 0.33.

Procedure

Subjects used a light pointer method (Seeber and Hafter, 2006, [6]) to indicate the perceived location of the lead-lag stimuli. After playback of a lead-lag pair a light-spot appeared at an azimuth of 0º. Using a trackball subjects adjusted the light-spot to the position where they perceived the combined lead-lag sound to come from and confirmed this by pressing a button. If lead-lag pairs were perceptually not fused and subjects heard two or more sounds they were instructed to indicate the most-left or most-right sound they heard in two separate runs (instruction „point-left" or „point-right"). Five responses were collected for each condition

(3 background noise levels plus in-quiet condition, 2 modulations, 2 lead directions, 9 delay times).

To assess localisation performance for the different degrees of modulation or SNR lead-only stimuli played from one of the target loudspeakers were localised with the same method. These trials were interwoven with the normal presentations of the lead-lag stimuli. Participants completed a training session before the actual experiment in which every stimulus condition was presented twice.

Results and Discussion

Results for all experimental conditions are shown in Figure 2 as a function of lead-lag delay. The medians and interquartile ranges for the pooled results of all participants are shown Data is arranged in trials where people pointed to the lead (shown as circles in Figure 2) and such where they pointed to the lag (shown as diamonds in Figure 2).

Influence of different background noise levels

The left column in Figure 2 shows data for unmodulated lead and lag sounds starting with the results collected in quiet conditions on top and for lower SNRs below. In quiet lead and lag are heard as a single percept for delays of up to 7 ms. For longer delays they start to split up and are localized independently close to their actual positions of ±30º for delays larger than 11 ms.

At SNRs of +10 and +5 dB a single fused percept for lead and lag close to the lead position is heard for delay times of up to 13 ms, a delay time where in quiet already two sounds are heard. For an even lower SNR of 0 dB images start to split up again at 7 ms, similar to the quiet condition.

Independent of the fusion of lead and lag also a clear trend for the localized direction can be found in the data. With lower SNRs the localized direction of the leading and lagging sound is pulled more towards the midline, in line with the results of Thurlow and Parks (1961) [7]. However, the localized direction of the lead-only stimuli, depicted at the very right in Figure 2, shows no such trend. This resistance against background noise for pure localization tasks was also reported by Braasch and Hartung (2002) [1] for a similar SNR.

Increased echo-thresholds in background noise were not reported by any of the earlier studies on this topic. In contrast, Thurlow and Parks (1961) [7] as well as Chiang and Freyman (1998) [2] reported reduced echo-thresholds in background noise. A possible explanation for the increase in our study may be found considering the ongoing nature of our stimuli. Also the lower coherence of the background noise used in this study may play a role here, since this might disrupt grouping or segregation cues in lead and lag in a different way than strongly correlated noise from the median plane does.

Influence of coherent amplitude modulation

The right panel in Figure 2 shows the results for coherent amplitude modulation of lead and lag, again starting with the quiet condition on top and going the lower SNRs below.

Comparing echo thresholds in modulated against those of unmodulated lead-lag stimuli a slight enhancement in the latter can be found. A fused percept of lead and lag in the

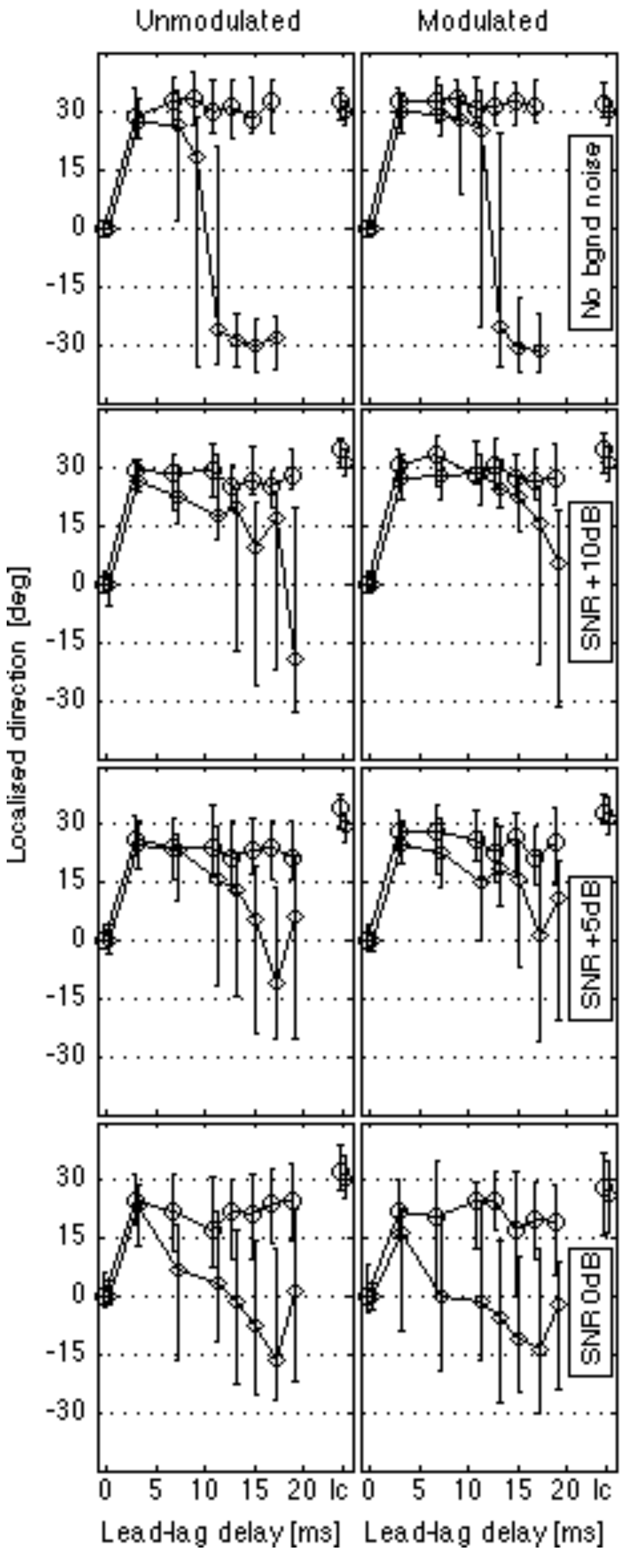

Figure 2: Localised direction of lead and lag stimuli as a function of lead-lag delay. Shown are medians and interquartiles for the pooled data of all participants. The lead was always located at +30**º.** Trials with participants pointing to the lead are depicted using circles, trials where they pointed to the lag are shown using diamonds. Left and right columns show results for unmodulated and modulated stimuli respectively, SNRs decrease from top to bottom.

unmodulated case is perceived up to 7 ms whereas in the modulated case lead and lag do not split up until 11 ms delay. This confirms the results obtained by Seeber (2008) [5] in his headphone study.

The trend for longer echo thresholds through amplitude modulation is preserved for moderate background noise levels: For SNRs of +10 and +5 dB a clear trend for enhanced fusion of lead and lag is observed as compared to the respective quiet conditions. However, for the SNR of 0 dB this effect disappears.

An explanation for the greater separation of lead and lag in the modulated condition at a SNR of 0 dB can be given considering the loudness of the target stimuli. The amplitude modulation reduces the average level of lead and lag by approximately 2.8 dB. This small reduction in level can lead to a big reduction in loudness due to the partially masked condition, making the targets more difficult to detect and thus to localize. This hypothesis is also supported by the data for the pure localisation task, which shows higher interquartile ranges for this condition compared to the others.

Summary

In summary we showed preliminary results for echo thresholds and localisation of long lead-lag stimuli in simulated diffuse background noise. The main findings are:

- For moderate background noise echo thresholds are longer than in quiet.
- With lower SNRs the perceived location of leading and lagging sound is pulled towards the frontal direction.
- Coherent amplitude modulation lead to longer echo thresholds in quiet and moderate background noise levels.

Increased fusion in background noise was not reported in earlier studies so far. We speculate that the nature of our ongoing stimuli provided either additional cues (e.g. envelope fluctuations or comb-filtering) for fusion or that background noise disrupted cues for segregation and thus this leads to the higher echo thresholds. However, it should be noted that so far only four subjects participated in the experiments and thus the results can only reveal trends. However, these trends seem to point to a clear direction.

Acknowledgements

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