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BINAURAL DETECTION THRESHOLDS ARE DIFFERENTLY AFFECTED BY INTERAURAL LEVEL DIFFERENCES IN S0 AND Sπ CONDITIONS

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ABSTRACT

The dependency of binaural detection thresholds on interaural level differences was investigated. Detection thresholds were measured for four discrete tones with either 100, 500, 1000 or 2500 Hz presented in diotic, uniform exciting noise (N0) via headphones using an adaptive forced choice method. The sine tones were presented either in-phase (S0) or anti-phasic (Sπ), and the interaural level difference (ILD) of the tone war varied within 15 dB.

Preliminary detection thresholds show that unmasking depends on the applied ILD. In the N0S0 condition, thresholds of low-frequency tones decrease by up to 7 dB for an ILD of 15 dB, which almost corresponds to the monaural threshold. This decrease with increasing ILD cannot be observed at 2500 Hz. In the N0Sπ condition, however, the increase in thresholds with increasing ILD is approximately equal for all frequencies. The resulting decrease in unmasking seems to follow the level decrease of the two summed sine tones with increasing ILD. In particular, the results of the N0Sπ condition suggest that the amount of binaural unmasking is more affected by the ILD than in the N0S0 condition.

Keywords: *binaural hearing, masking, dichotic listening*

1. INTRODUCTION

It is well-known from the literature that correlation differences, e.g. due to a phase shifts in the ear signals, are helpful for detection tasks in noise [1 – 4], especially for low-frequency signals. McFadden and Pasanen [5] showed that for high frequency signals at 4 kHz in an N0Sπ condition, binaural unmasking occurs most likely because of ongoing ILDs since the phase differences in the envelope cannot be evaluated at low signal-to-noise ratios. These previous studies concluded that interaural phase changes are more effectively evaluated at frequencies below 1.5 kHz and ILDs at higher frequencies. One might assume that this dependency on frequency should also be observable for detection thresholds with both interaural cues combined in the target stimulus. Furthermore, one can rise the hypothesis that increasing the ILD should affect the detection threshold for high frequency signals in noise more than for low frequency signals. Hafter et al. [6] found that the binaural masking level difference for low- and high-frequency bandpass clicks were similar across different ILDs applied to the signals, with 7.2 and 8.0 dB, respectively. It seems possible that increasing ILDs decreases interaural coherence in noise and thus affects detection thresholds as well. The aim of the current preliminary study is to investigate the influence of an ILD, applied to target tones at different frequencies, combined with an interaural phase shift, on detection thresholds in correlated, diotically presented noise. Therefore, detection thresholds were measured for low and high frequency sine tones and different ILD conditions either in an N0S0 or in an N0Sπ condition.

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2. EXPERIMENTAL METHODS

2.1 Stimuli

Sine tones with either 100, 500, 1000 or 2500 Hz were used to measure detection thresholds in diotically presented uniform exciting noise, which is designed to have the same energy in each auditory filter [7].
The target sine tones had an effective duration of 500 ms at 90% of the target signal's amplitude, with 10 ms Gaussian-shaped rise and fall times. For the S0 condition, the target sine tones, presented on each ear, were in-phase, whereas for the Sπ condition, the target sine tone presented one of the ears was antiphasic. The ear with the phase shift is further referred to as the contralateral ear, whereas the other without phase shift is considered the ipsilateral ear.
In addition, different ILDs were applied by reducing the target signal's level on the contralateral ear. Four ILD conditions were tested, 0 dB, 5 dB, and 15 dB, and a monaural presentation to the ipsilateral ear, which correspond to an infinite ILD.
The masking noise was band-limited from 20 Hz to 3 kHz to ensure masking of all tested frequencies by the same amount. It had an overall duration of 900 ms with 30 ms Gaussian rise and fall times. The level of the diotic noise was set to 65 dB SPL. The target sine tone was time-centered within the noise masker.
The stimuli were presented in a double-walled sound-isolated booth via HD 600 headphones (Sennheiser GmbH & Co KG) connected to a custom made, calibrated high-quality digital-to-analog-converter headphone amplifier [8] fed with a 24-bit digital audio stream at a sampling frequency of 44.1 kHz.

2.2 Experimental procedure

The detection thresholds of the sine tones in uniform exciting noise were measured with a three-interval three-alternative-forced-choice method (3I-3AFC) using a three-down/one-up adaptive staircase procedure. Three intervals of the diotic noise masker, separated by an inter-stimulus-interval of 500 ms, were presented to the listener. To one of these intervals the target test tone was added. The participant's task was to indicate in which of the three noise intervals they perceived the target sine tone by pressing the corresponding number on a keyboard. The initial level of the probe tone on the ipsilateral ear was set to 65 dB SPL. The initial step size was 5 dB, after the first two reversals it was set to 2 dB and to 1 dB final step size after two more reversals. The decrease in level was applied to the target tone on both ears equally. The last eight reversals at the final step size were used to calculate the threshold level at the ipsilateral ear by taking the mean.
The order of all tested combinations of the sine tone frequency, the S0 and Sπ condition and the applied ILD to the contralateral ear were randomized. The tracks were not interleaved, so that the participant had to finish one track before the next random test condition started. Each participant finished one track for an ILD and a phase shift applied to either the left or the right ear separately, resulting in 64 tracks. On average participants finished the experiment in 3 hours and 48 minutes.

2.3 Participants

Four male participants volunteered in this experiment. Their age ranged from 23 to 31 years (mean: 26.5 yr., SD: 3.5). All participants had normal hearing thresholds with a hearing loss less than 15 dB up to 8 kHz as assessed with a clinical audiometer. They gave written consent and were not payed for participating in the experiment. The study was approved by the ethics committee of the TUM, 65/18S.

3. RESULTS

Since the detection thresholds measured for an applied ILD and phase shift to either the left or the right ear did not differ from each other, the thresholds were derived by averaging across 2x8=16 reversals at the final step size from the left and right condition for further analysis. Furthermore, the data is presented as the differences in detection thresholds relative to a 0 dB ILD condition individually for each frequency and interaural phase condition.

3.1 Detection in S0 conditions with ILDs

The threshold changes relative to the 0 dB ILD conditions for the N0S0 condition are shown in Figure 1 for all ILD conditions and tested frequencies. With increasing ILD, the threshold at low frequencies decreases by 2 dB for the -5 dB ILD condition, and decreases by 6 dB for an ILD of -15 dB. The observed change for 100 and 500 Hz is similar which can be seen from the largely overlapping quartiles for all tested ILD conditions. The threshold change for a monaural listening situation is only marginally larger than for the -15 dB ILD condition for both low-frequency signals. This shows that with an ILD of 15 dB at the contralateral ear the detection threshold is almost at monaural performance.
For higher frequencies, the effect of ILD on threshold is less than at low frequencies. For 1 kHz the decrease in detection threshold is only 2 dB for an ILD of 15 dB compared to the

0 dB ILD condition. For 2.5 kHz the threshold change is almost 0 dB for all tested ILD conditions. The results suggest that the influence of the ILD on binaural detection thresholds in an N0S0 situation is highly frequency dependent.

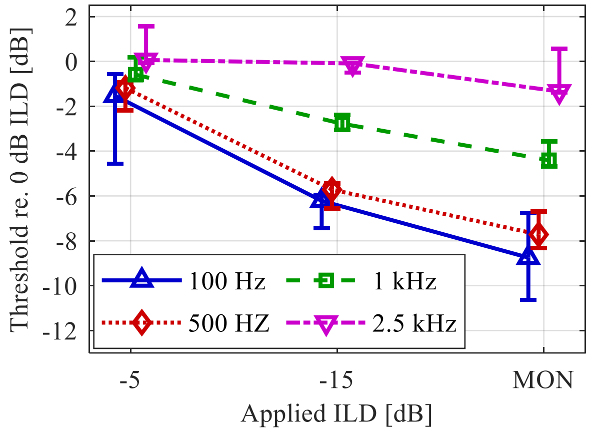

Figure 1: Difference in detection thresholds for different tested ILD conditions relative to the measured detection threshold with 0 dB ILD in an N0S0 condition. The different markers, connected with lines for better readability, correspond to different tested frequencies. The decrease in detection threshold with increasing ILD is larger for low frequency signals than for higher frequencies. For 2.5 kHz almost no decrease can be observed.

3.2 Detection in Sπ cinditions with ILDs

Figure 2 shows the threshold changes relative to 0 dB ILD conditions for an N0Sπ condition for all ILD conditions and tested frequencies. Unlike the results for an N0S0 condition, shown in section 3.1, the results for the N0Sπ condition show an increase in detection threshold with increasing ILD, since the difference relative to 0 dB ILD becomes positive. The threshold increases by 2.5 dB for the 5 dB ILD condition up to 6 dB for a monaural listening condition. Also here thresholds measured with 15 dB ILD at the contralateral ear are similar to thresholds with a monaural target presentation. The measured data also suggest that this increase is almost frequency independent, since the differences in threshold change across frequencies are small and the quartiles overlap in nearly all ILD conditions.

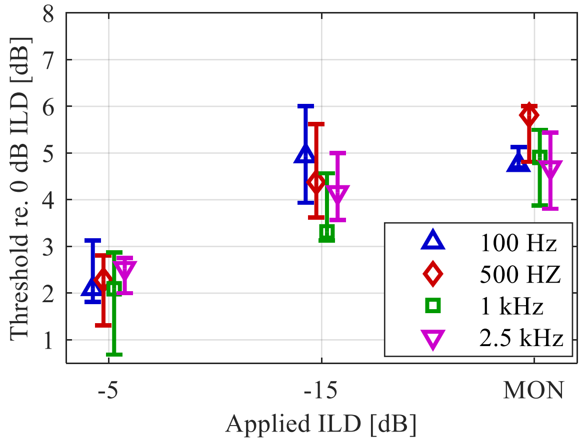

Figure 2: Difference in detection thresholds for different tested ILD conditions relative to the measured detection threshold with 0 dB ILD in an N0Sπ condition. The different markers correspond to different tested frequencies. The increase in detection threshold with increasing ILD is similar for all tested sine tone frequencies.

4. CONCLUSION

This study investigated the influence of an interaural level difference on detection thresholds of sine tones in uniform exciting bandpass noise for either an N0S0 or an N0Sπ condition. From the preliminary data collected so far it can be seen that the ILD of the target signal has a different impact on the detection thresholds in an N0S0 than in an N0Sπ condition. Furthermore, the data suggest that the influence of ILD is independent of the signal frequency only for a N0Sπ condition, thus confirming the results of van der Hejiden and Trahiotis [3] and Bernstein and Trahiotis [9]. These two studies showed that binaural unmasking is independent of the center frequency of the signal and whether the binaural information is presented in the fine structure or in the envelope. This is not observed in the current results for a N0S0 condition. Here the influence of the ILD is strongly frequency-dependent.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

[1] I.J. Hirsh, "The influence of interaural phase on interaural summation and inhibition," *Journal of the Acousticaol Society of America*, vol. 20, pp. 536–544, 1948.

[2] D.E. Robinson and L.A. Jeffress, "Effect of varying the interaural noise correlation on the detectability of tonal signals." *Journal of the Acoustical Society of America*, vol. 65, pp. 1947–1952, 1965.

[3] M. van der Hejiden and C. Trahiotis, "Binaural detection as a function of interaural correlation and bandwidth of masking," *Journal of the Acoustical Society of America*, vol. 103, pp. 1609–1614, 1998.

[4] N.F. Bischof, P.G. Aublin and B.U. Seeber, "Fast processing models effects of reflections on binaural unmasking," *Acta Acustica*, vol. 7, no. 11, pp. 1–18, 2023.

[5] D. McFadden and E.G. Pasanen, "Binaural detection at high frequencies with time-delayed waveforms," *Journal of the Acoustical Society of America*, vol. 63, pp. 1120–1131, 1978.

[6] E.R. Hafter, R.H. Dye, J.M. Nuetzel, and H. Aronow, "Difference thresholds for interaural intensity," *Journal of the Acoustical Society of America*, vol. 61, pp. 829–834, 1977.

[7] F. Fastl and E. Zwicker: *Psychoacoustics Facts and Models.* Berlin Heidelberg, Springer, 2007.

[8] M. Welsch: *Design of a low-noise headphone amplifier with digital-to-analog converter for psychoacoustic experiments*, Master's thesis, Technical University of Munich, Germany, 2015.

[9] L.R. Bernstein and C. Trahiotis, "Accounting for binaural detection as a function of masker interaural correlation: effects of center frequency and bandwidth," *Journal of the Acoustical Society of America*, vol. 136, pp 3211–3220, 2014.