Modeling Spectral Integration in Binaural Signal Detection

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Abstract: Estimates of critical bandwidths in binaural experiments vary considerably across experimental conditions. For masking experiments using notched noise maskers and experiments with a frequency-dependent interaural masker correlation, bandwidth estimates agree with those from monaural experiments. However, if auditory bandwidths are estimated from binaural band-widening masking experiments, the effective bandwidth is usually a factor 2 to 3 times larger than monaural estimates. One often ignored detail is that this difference between monaural and binaural estimates decreases with decreasing masker level [Hall et al., J. Acoust. Soc. Am. 73, 894-898 (1983)]. Using the binaural model described by Breebaart et al. (this issue), we have simulated the binaural experiments described above. We can show that, without any parameter changes in the model, basically all relevant conditions can be modeled accurately, including the band-widening and spectral integration experiments. In agreement with the scheme discussed by Kohlrausch et al. (this issue), detection in binaural narrowband-noise conditions is improved by analyzing the internal representation in several adjacent filters. We conclude that the primary cause for the so-called "wider binaural critical band" as compared to the monaural critical band is the absence of this detection advantage in monaural random-noise conditions.

INTRODUCTION

It is generally accepted that the auditory system splits the incoming sounds in several band-limited signals. The bandwidth of the auditory filters as a function of frequency is well established (1). One unresolved issue concerning the band-filter concept is that for certain binaural conditions, the bandwidth of the auditory filters seems wider than results from monaural experiments. Hall et al. (2) measured the detection threshold for an antiphase test signal in a diotic noise masker as a function of the bandwidth and spectrum level of the noise. They found that for masker levels well above the absolute threshold, the effective auditory filter bandwidth amounts 2 to 3 times the value reported from monaural experiments. In contrast, when they estimated the auditory filter bandwidth from experiments with notched noise, the estimated filter bandwidths were in line with estimates from monaural experiments. It is proposed that this discrepancy results from the auditory system's ability to combine information across auditory filters. Using the binaural signal-detection model from Breebaart et al. (this issue), it is shown that with this concept we can quantitatively predict binaural masked thresholds and apparent discrepancies between bandwidth estimates across experimental paradigms.

ACROSS-FREQUENCY INTEGRATION

The following scheme is based on the binaural signal-detection model proposed by Breebaart et al. (this issue). It is assumed that signals arriving at both ears are preprocessed by a peripheral preprocessing stage (including bandpass filtering, reduction of phase-locking and adaptation) and subsequently the temporally integrated difference signal, \( U_i \), is computed for each auditory filter, \( i \). For simplicity, no internal interaural delays or interaural intensity factors are considered. It is then assumed that the internal representation is degraded by internal noise; an independent random variable, \( \varepsilon_i \), is added to the difference signal, \( U_i \), of each auditory filter. For NoSt conditions, it is this internal noise which limits detection. The model extracts one decision variable, \( U \) by optimally weighting \( (w_i) \) and summing the values \( U_i \) of all auditory filters.

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U = \sum_i w_i (U_i + \varepsilon_i)
\]

The effect of masker bandwidth on the across-frequency integration is demonstrated in Fig. 1 which shows the values of \( U_i \) as a function of the auditory-filter number for a 500-Hz NoSt condition. The masker has a fixed spectral energy density of 30 dB/Hz and the level of the signal amounts to 40 dB. The solid line represents a masker bandwidth of 50 Hz, the dashed line 100 Hz, the dash-dotted line 200 Hz and the dotted line 400 Hz. The difference variable is largest in the on-frequency filter (filter number 10). For narrow maskers, also the off-frequency channels have high values of \( U_i \) and do thus provide useful information for detecting the signal; the excitation is spread. With increasing masker level, this spreading will increase since more and more filters receive stimulus parts that are above the absolute threshold. The summation of information across auditory filters will increase the sensitivity.
for the presence of the test signal, due to the fact that the random variables $\varepsilon_k$ are uncorrelated in the various auditory filters. Furthermore, this increase in sensitivity will be larger at higher masker levels due to a wider spreading. For maskers of subcritical bandwidth, the difference signal decreases with increasing masker bandwidth due to the increasing amount of masker power in the auditory filters. For supracritical bandwidths, the difference signal in the on-frequency filter remains constant with increases of masker bandwidth, while in the off-frequency filters, $U_i$ decreases, leading to increasing thresholds even beyond the critical bandwidth.

**FIGURE 1.** Panel A: Interaural differences $U_i$ as a function of auditory-filter number for masker bandwidths of 50 Hz (solid line) 100 Hz (dashed line), 200 Hz (dash-dotted line) and 400 Hz (dotted line). Panel B: Detection thresholds for an NOSZ condition as a function of the bandwidth of a constant-spectral-level noise. The open symbols represent experimental data from Hall et al. (2), the filled symbols are model predictions. Squares: $N_o=50 \text{ dB/Hz}$, upward triangles: $N_o=30 \text{ dB/Hz}$, downward triangles: $10 \text{ dB/Hz}$. Panel C is the same as panel B but for a broadband masker with a notch of variable width.

**MODEL PREDICTIONS**

To demonstrate that the across-frequency integration scheme can quantitatively account for discrepancies between estimates of critical bands across experimental paradigms, we determined the thresholds for a 500-Hz NOSZ condition with a masker of fixed spectral energy density (10, 30 and 50 dB/Hz) as a function of the bandwidth of the masker. The model predictions are shown by the solid symbols in Fig. 1, panel B. The open symbols represent experimental data adapted from Hall et al. (2). Spectral levels of 50, 30 and 10 dB/Hz are shown by the squares, upward triangles and downward triangles, respectively. For all three noise levels, the thresholds first increase with increasing bandwidth up to a few hundred Hertz. However, the bandwidth at which the thresholds stop increasing is larger for higher noise levels. Moreover, the effective critical bandwidth is larger than the reported monaural bandwidth. The level dependence of the effective critical bandwidth results from the widening excitation pattern along the internal frequency axis with higher noise levels. Panel C shows thresholds as a function of a notch bandwidth centered around the signal frequency. If we take the 3 dB threshold improvement as a measure of frequency resolution, the bandwidth corresponds to the monaural critical bandwidth for both experimental data and model predictions. Hence in this condition, across-frequency integration does not enhance the performance, since all off-frequency filters are masked by the broadband noise.

**CONCLUSION**

The linear weighted addition of separate channel information reduces the internal error in the case of a narrowband masker, due to the fact that the internal error variables are uncorrelated. With increasing masker bandwidth, the sensitivity for the test signal decreases due to masking of more and more off-frequency filters, disabling the internal error reduction through spectral integration. This approach can qualitatively and quantitatively account for the discrepancies between estimates of critical bandwidths across experimental paradigms.

**REFERENCES**