SPATIAL UNMASKING OF CHIRP TRAINS IN A SIMULATED ANECHOIC ENVIRONMENT: BEHAVIORAL RESULTS AND MODEL PREDICTIONS

#935

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1. ABSTRACT

Gilkey and Good (1995) hypothesized that improvements in detection with spatial separation of a signal (S) and noise (N) come about due to low-frequency binaural effects and/or high-frequency changes in the signal-to-noise ratio (SNR). The current study examines the relative importance of low and high frequency (binaural and energetic) cues for broadband stimuli.

Detection thresholds are measured for a broadband 40-Hz chirp train in the presence of a broadband noise for multiple spatial configurations (using procedures and stimuli similar to Lane et al., 2003). Results are compared to model predictions to test whether thresholds are determined by the best single frequency channel or if information is integrated across channels. Various S and N spatial configurations were simulated using non-individualized head-related transfer functions. Measurements were made for both broadband and lowpass-filtered stimuli; highpass and narrowband conditions were measured for a subset of conditions.

Results suggest that broadband thresholds depend primarily on high-frequency monaural cues. Low-frequency information and binaural processing do not contribute significantly to broadband performance. For lowpass stimuli, spatial unmasking is smaller in magnitude; energetic factors still dominate.

Overall, results support the hypothesis that information is integrated across multiple frequency channels.

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2. MOTIVATION

"Spatial unmasking" is an improvement in signal detection threshold when signal and noise are spatially separated.

Spatial unmasking of pure-tone stimuli depends on
- energetic factors (change in the signal-to-noise energy ratio, SNR, due to change in location
- binaural processing (improvement in signal detectability due to signal and noise interaural cues)

Spatial unmasking of broadband stimuli depends on (Gilkey and Good, 1995)
- energetic factors for all stimuli
- additional binaural factors for low-frequency stimuli

Two possibilities for broadband stimuli
- auditory system integrates information across multiple channels
- auditory system chooses single best channel with most favorable SNR ("single-best-filter" model)

Best channel hypothesis supported by comparison of single-unit thresholds from cat's inferior colliculus to human behavioral data (Lane et al., 2003).

CURRENT STUDY

Test the single-best-filter hypothesis of spatial unmasking for broadband and lowpass stimuli
- measure spatial unmasking for broadband and lowpass chirp-train signals in noise
- compare performance to single-best-filter predictions

3. EXPERIMENTAL METHODS

SUBJECTS

- 3F, 2M listeners, normal hearing

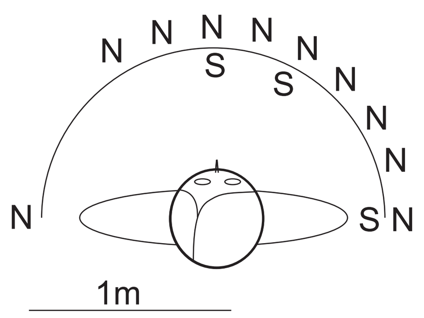
SIMULATION

- simulated anechoic auditory space
- all sounds at distance of 1 m (see Fig. 1)
- signal fixed at 0, 30, or 90û in right frontal hemifield
  - multiple noise azimuths
  - HRTFs used in simulation:
  - non-individual human HRTFs measured using MLS

OVERALL PROCEDURE

- each spatial configuration tested at least 3x
- 3 blocks, each measuring all thresholds in random order

FIGURE 1. Simulated positions of signal (S) and noise (N)



STIMULI

Noises: 250-ms white noise bursts
- broadband: 200-14000 Hz
- lowpass: 200-2000 Hz

Signal: 200-ms 40-Hz chirp train
- broadband: 300-12000 Hz
- lowpass: 300-1500 Hz
- narrowband: one or more equivalent rectangular bandwidths (ERB)
- spectrum level 14 dB SPL/Hz (broadband 56 dB SPL)

EQUIPMENT

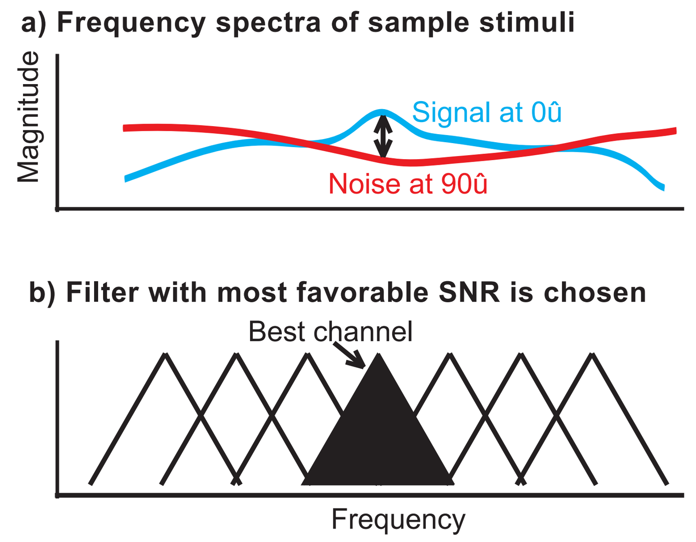
- stimuli generated using TDT PD1, PA4, SM3, HB6
- Etymotic Research ER-1 insert ear-phones
- response and feedback provided via personal computer

THRESHOLD DETERMINATION

- 3-down-1-up adaptive procedure (tracking 79.4% correct) varying M level
- three-interval, two-alternative forced choice task

4. MODEL

FIGURE 2. Schematic of the single-best-filter model.



Filterbank: 60 log-spaced gammatone filters per ear (Johannesma, 1972)

Two filter widths: standard and narrow (scaling of 2.5) to test Shera et al. (2002) suggested filter width

SNR computed in each filter

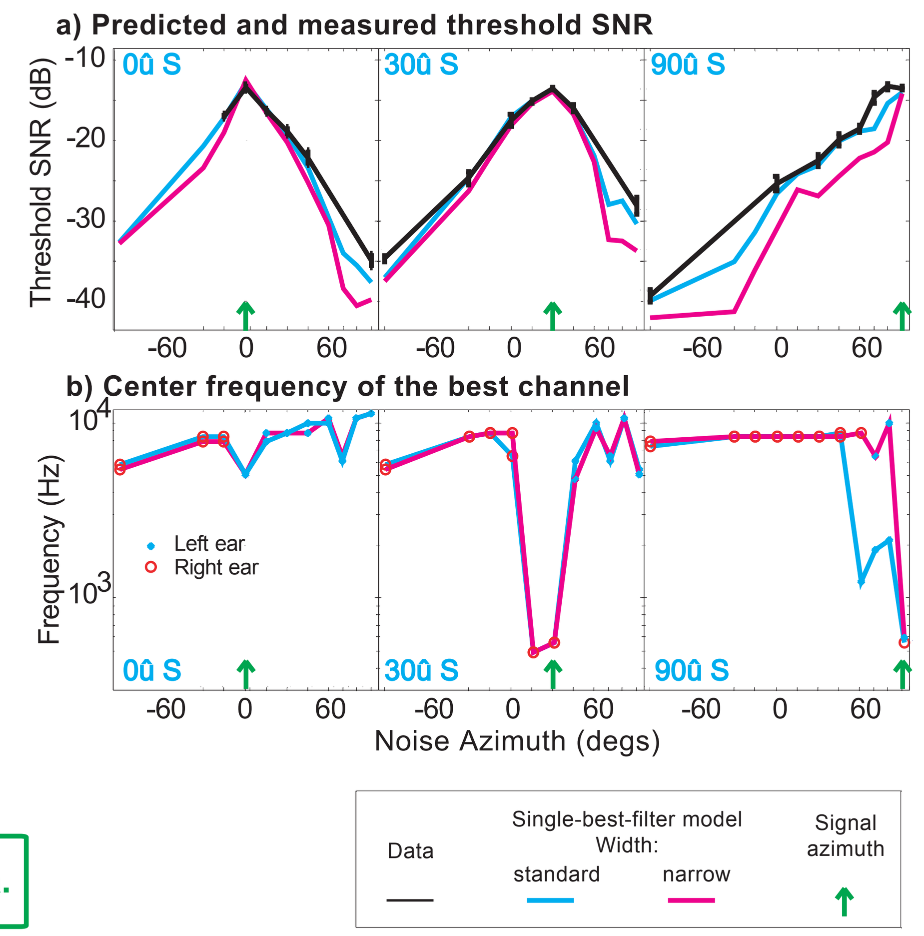
Single best filter found across all120 filters

Predicted threshold = -SNR - T_0 (T_0 is a model parameter)

5. RESULTS

A. BROADBAND STIMULI

FIGURE 3. Spatial unmasking of broadband stimuli. a) Measured (subject mean and standard error) and predicted thresholds as a function of noise azimuth. b) Center frequency and ear (left/right) of single best filter.



Data
- spatial unmasking of nearly 30 dB

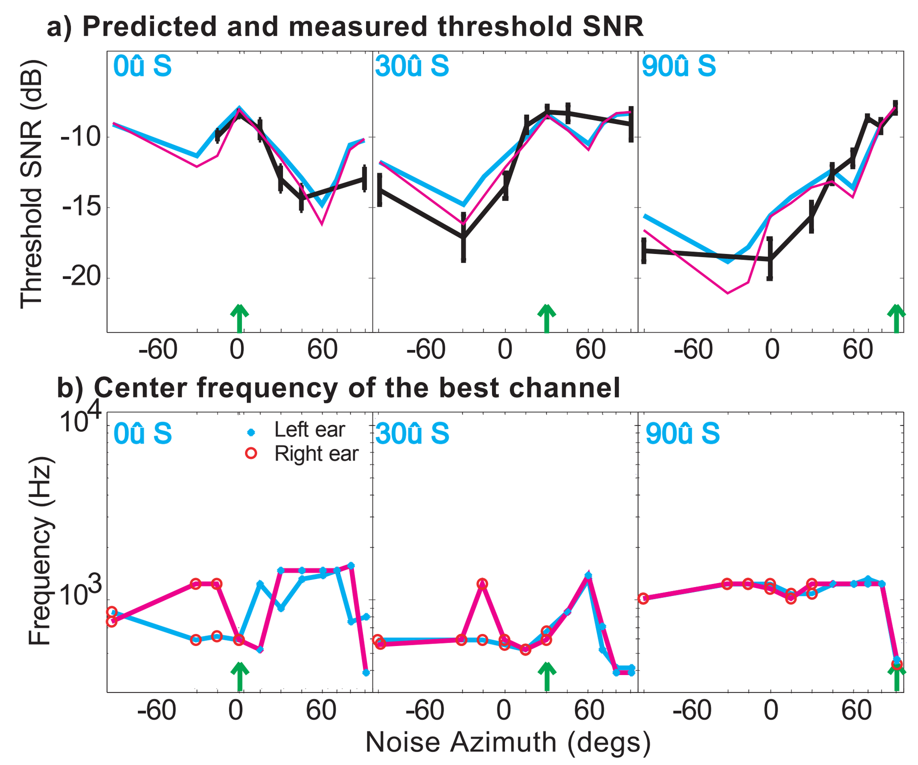
Single-best-filter model (standard width)
- produces accurate predictions (within 4 dB)
- tends to overestimate spatial unmasking
- single best filter has high frequency, so ...
- binaural processing unlikely to contribute

Single-best-filter model (narrow width):
- overestimates unmasking in many configurations

The single-best-filter model predicts broadband data.

B. LOWPASS STIMULI

FIGURE 4. Spatial unmasking of lowpass stimuli (as in Fig. 3).



Data
- thresholds worse than broadband
- spatial unmasking less than broadband

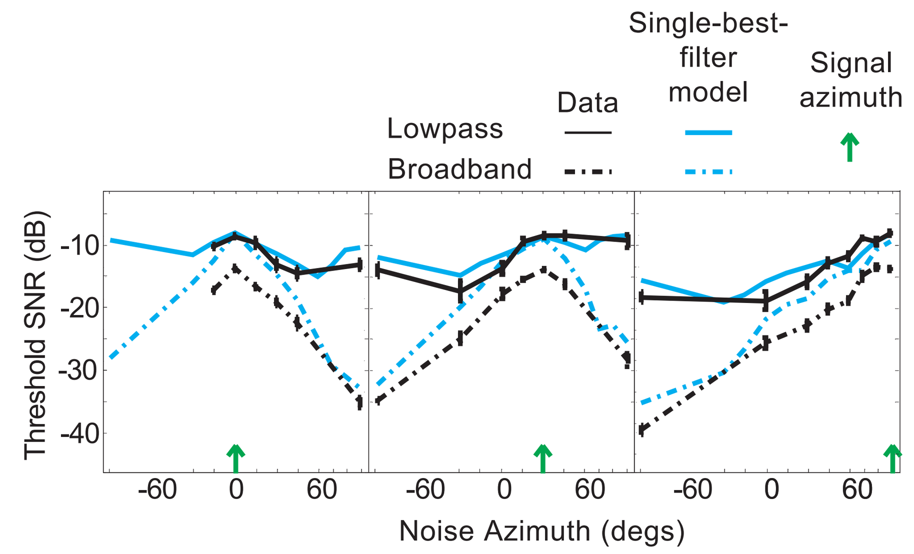
Single-best-filter model
- produces accurate predictions (within 3 dB)
- narrow and standard-width filters equally accurate
- generally underestimates unmasking
- underestimation may be due to binaural processing

The single-best-filter model predicts lowpass data.

5. RESULTS (cont.)

C. BROADBAND VS. LOWPASS STIMULI

FIGURE 5. Comparison of broadband and lowpass thresholds.



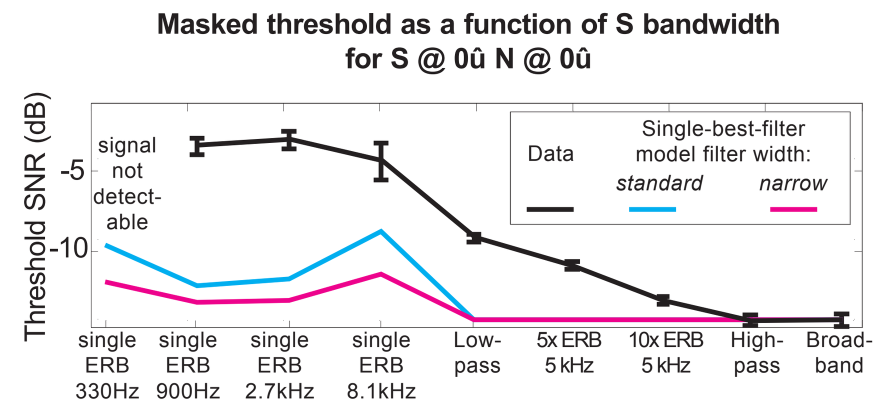
Data
- for all azimuths, broadband thresholds better than lowpass

Single-best-filter model
- predicts roughly equal thresholds for broadband and lowpass

The single-best-filter model cannot predict lowpass and broadband data at the same time.

D. NARROWBAND VS. OTHER STIMULI

FIGURE 6. Effect of stimulus bandwidth on threshold for co-located signal and masker: data and predictions



Data
- thresholds improve with increasing bandwidth
- highpass and broadband thresholds similar
- 10 ERB thresholds approach broadband
- single ERB thresholds
  - 10 dB worse than broadband
  - approximately equal, indicating roughly equal SNR and information in each ERB

Single-best-filter model predicts approximately equal thresholds for all conditions.

The single-best-filter model fails to predict thresholds' bandwidth dependence.

6. CONCLUSIONS

DATA

For these broadband stimuli, spatial unmasking
- improves thresholds by nearly 30 dB
- is dominated by energetic effects in the high frequencies

For these lowpass stimuli, spatial unmasking
- improves thresholds by at most 12 dB
- is dominated by low-frequency energetic effects

Detection thresholds improve with bandwidth.

MODEL

The single-best-filter model predicts the amount of spatial unmasking for broadband ***or*** lowpass stimuli.

However, the model threshold parameter must differ in order to achieve these fits.

More generally, the model cannot predict the observed dependence on signal bandwidth.

DISCUSSION

It is unlikely that any single-best-filter SNR-based model (regardless of exact implementation) can account for these results.

For broadband signal detection in noise, there appears to be across-frequency integration.

Only a model that integrates information across multiple frequency channels is likely to be able to account for these observations.

7. REFERENCES

Gilkey, R. H. and Good, M. D. (1995) "Effects of frequency on free-field masking," Human Factors 37(4): 835-843.

Johannesma P. I. M. (1972). "The pre-response stimulus ensemble of neurons in the cochlear nucleus," in IPO Symposium on Hearing Theory, ed. B.L. Cardozo, E. de Boer, & R. Plomp (IPO, Eindhoven, The Netherlands), pp. 58-69.

Lane, C. C., Delgutte, B., and Colburn, H. S. (2003) "A Population of ITD-Sensitive Units in the Cat Inferior Colliculus Shows Correlates of Spatial Release from Masking," ARO Abstract #706, Session Q10.

Shera, C. A., Guinan, Jr, J. J., and Oxenham, A. J. (2002) "Revised estimates of human cochlear tuning from otoacoustic and behavioral measurements," Proc. Natl. Acad. Sci. USA 99:3318-3323.