Effects of Spectral Variability on Monaural Azimuthal Localization

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Introduction and Background

The ability to utilize interaural difference cues to determine the location of a sound source is a benefit of binaural hearing. Monaural listeners must rely on the overall level and spectral shape to determine if a sound is to the left or right. Unfortunately, these spectral cues are unreliable because many sounds (like speech) have levels and spectral shapes that vary. Here, we tested the ability of subjects to monaurally discriminate between virtual sources, located to the left and right of the midline, that were producing stimuli with random overall levels and spectral shapes.

Traditional linear decision models provide predictions about the effects of spectral variability on discrimination performance. These models assume that each frequency component of the stimulus is given a certain weight. These models allow the weights to vary across individuals, but assumes that for each individual the weights are fixed and applied without any noise. Here, we extend these models of spectral shape discrimination to allow for noise in the weighting of each component.

Methods

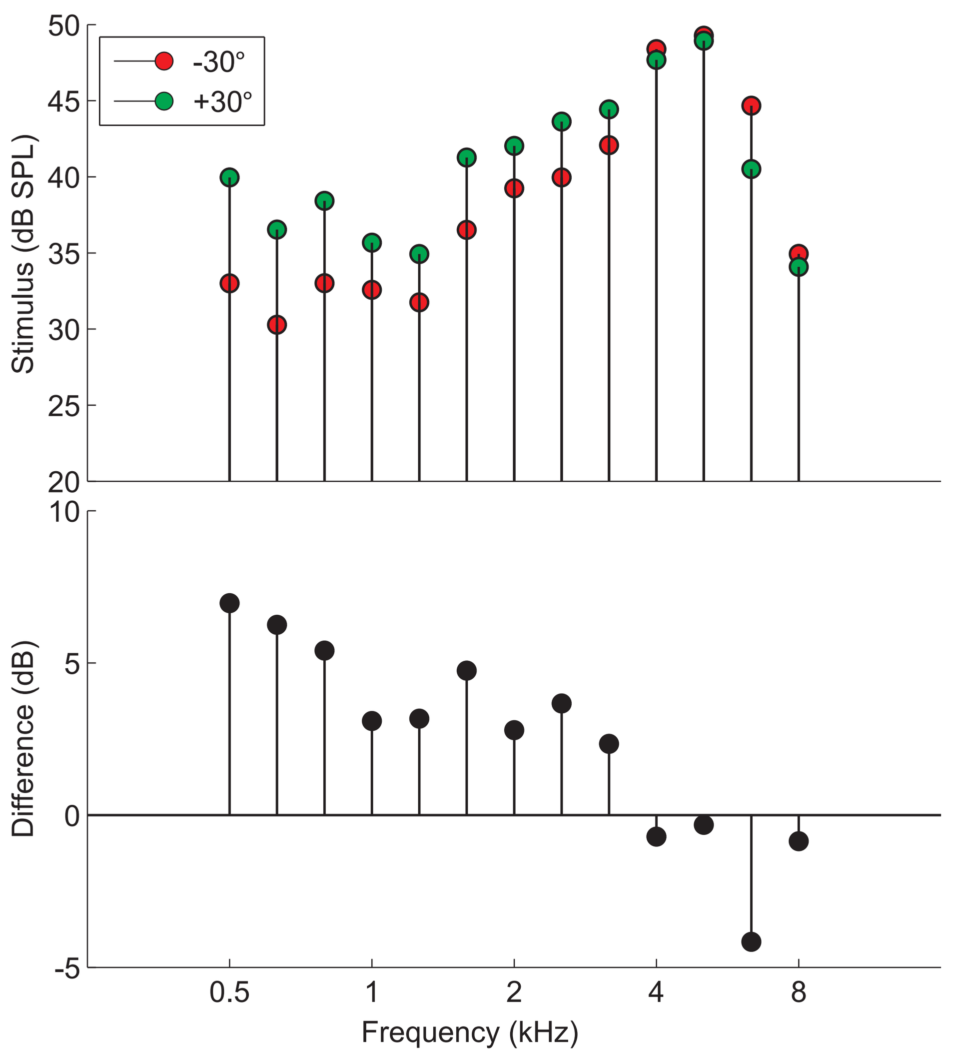

Figure 1. Shows the two reference spectral shapes, prior to the overall level randomization and spectral shape perturbation, to be discriminated (top panel) and the difference in the spectral shapes (bottom panel).

- Task is to discriminate between sources located ±30° from midline when listening to virtual sources presented monaurally over headphones
- Three normal-hearing subjects used KEMAR HRTFs
- Feedback provided after every trial
- 250 ms stimuli
- ~55 dB SPL overall level of the stimuli for both the left and right virtual sources prior to the overall level randomization and spectral-shape perturbation
- Overall level was random across trials; one standard deviation σ_L of 8 dB was used
- Spectral shape was perturbed across trials by independently varying the levels of each frequency component; five different standard deviations σ_E were used (0, 1, 2, 4, and 8 dB)

Discrimination Results

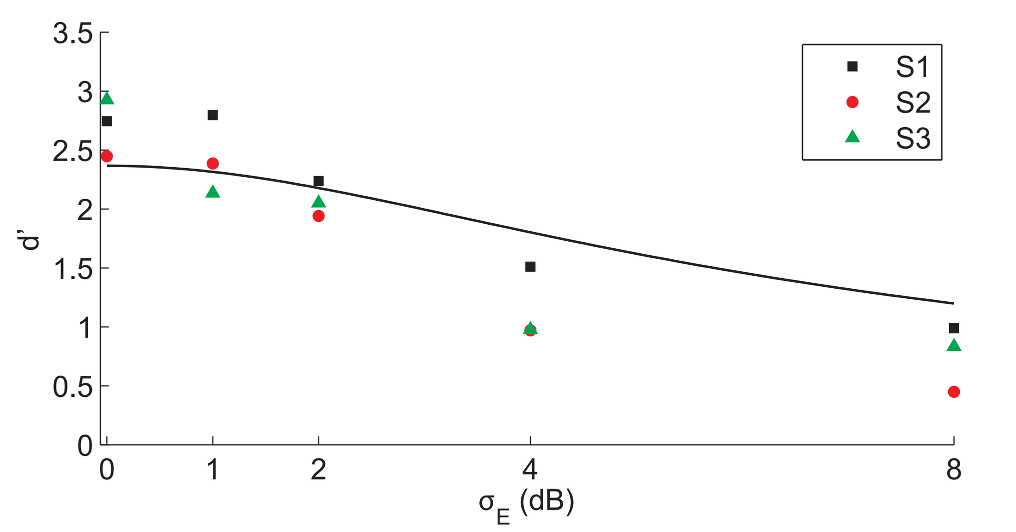

Figure 2. Shows d' as a function of the magnitude of the external variability σ_E in the stimulus spectrum. The standard deviation of the overall level σ_L was 8 dB. The solid line is the prediction of a linear decision model with optimal weights and an internal channel noise σ_I of 4.7 dB.

- With σ_E = 0 dB and σ_L = 8 dB subjects discriminate between ±30° nearly perfectly
- With σ_E = 8 dB and σ_L = 8 dB the best subjects can still reliably discriminate ±30°
- Performance falls off faster than predicted by a linear decision model with optimal weights and an internal channel noise

Linear Decision Model Predictions

We extend the linear decision model to include a weighting noise ε_w in addition to the internal channel noise ε_i and the external noise ε_e. For this model the decision variable Y and d' are given by:

$$Y = \sum (w + \epsilon_w)\left(x + \epsilon_e + \epsilon_i - \frac{X_1 + X_2}{2}\right)$$

$$d' = \frac{\sum w(X_1 - X_2)}{\sqrt{\sigma_e^2 \|w\|^2 + \sigma_L^2 N^2 \bar{w}^2 + \sigma_i^2 \|w\|^2 + N\sigma_w^2(\sigma_e^2 + \sigma_i^2) + \sigma_w^2 \sum \left(\frac{X_1 - X_2}{2}\right)^2}}$$

- The weighting noise ε_w changes the variance of the decision variable Y, but does not change the mean of Y

Model was fitted to the data with
- Optimal weights with internal channel noise
- Measured weights with internal channel noise
- Measured weights with internal channel noise and weighting noise

- Without weighting noise the predicted d' does not fall as fast as the measured d'
- With weighting noise the model predicts 93.9 percent of the variance in the measured values of d'

	Optimal weights with only channel noise		Measured weights with only channel noise		Measured weights with both channel noise and weighting noise		
	σ_I (dB)	% Var.	σ_I (dB)	% Var.	σ_I (dB)	σ_W (dB)	% Var.
S1	4.1	85.3	3.9	90.8	2.0	0.3	97.8
S2	5.2	60.7	1.7	88.7	0.5	0.2	95.5
S3	4.9	60.9	2.9	69.6	0.7	0.3	88.0

Table 1. Parameters (σ_w and σ_i) used in fitting the model and the percent of the variability in the measured d' accounted for by the model predictions.

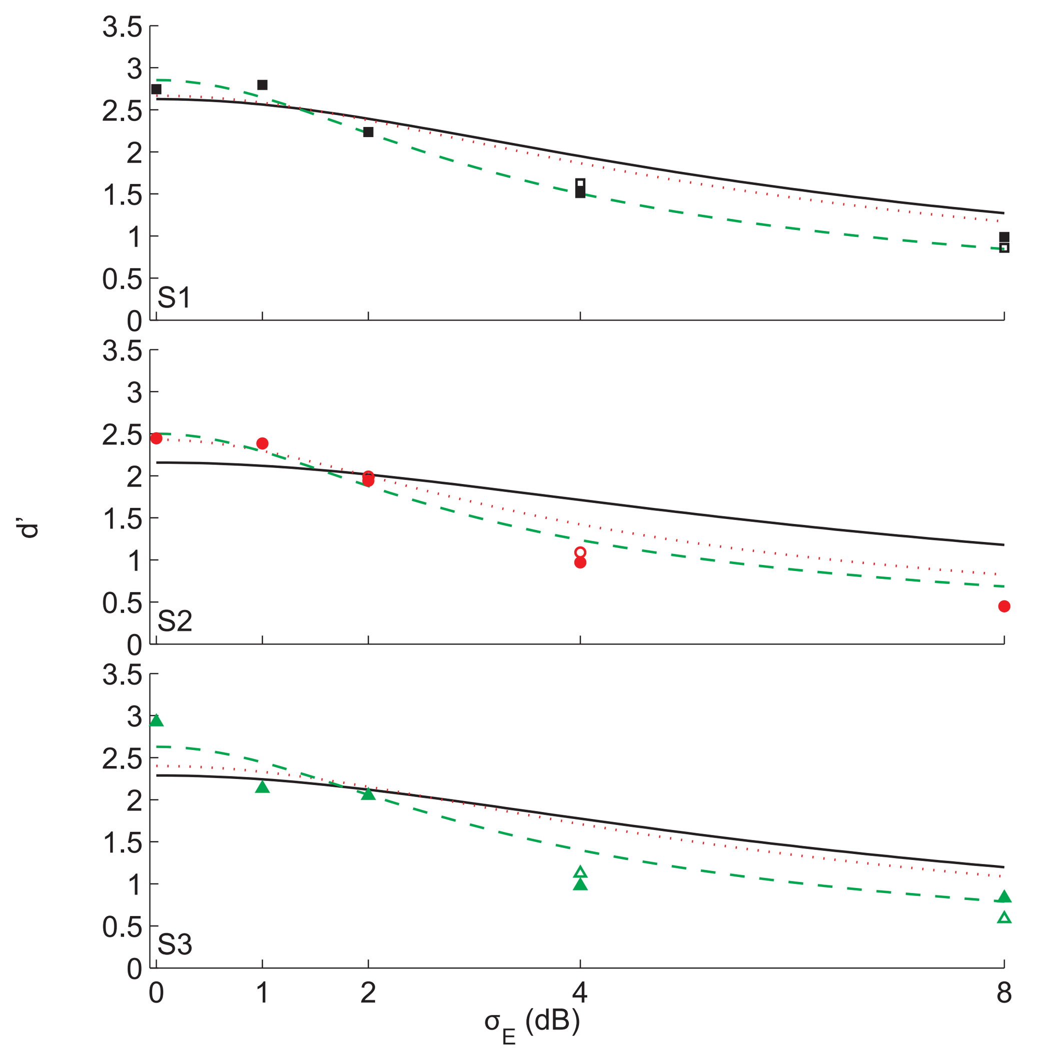

Figure 4. Shows the predictions of an observer with optimal weights and internal channel noise (solid black), the measured weights and internal channel noise (red dotted), and the measured weights and both internal channel noise and weighting noise (green dashed) for each subject. The closed symbols are the d' shown in Fig. 2, while the open symbols are the estimates of d' from the trials used to measure the weights.

Relative Weights

- To obtain the same d', a linear decision model with non-optimal weights requires less internal noise (smaller σ_I) than a linear decision model with optimal weights
- Reducing σ_I results in the performance of a linear decision model falling off faster
- For each subject, weights were measured with two different values of σ_E, these measurements are independent of the measurements of d' shown in Fig. 2

- Weighting pattern efficiency η_W and the weight given to the overall level (the sum of the weights) Σw varies across the subjects
- For each subject, the weighting patterns are nearly independent of σ_E (not shown)
- The weights reveal differences amongst the subjects which are not apparent in the measurements of d'

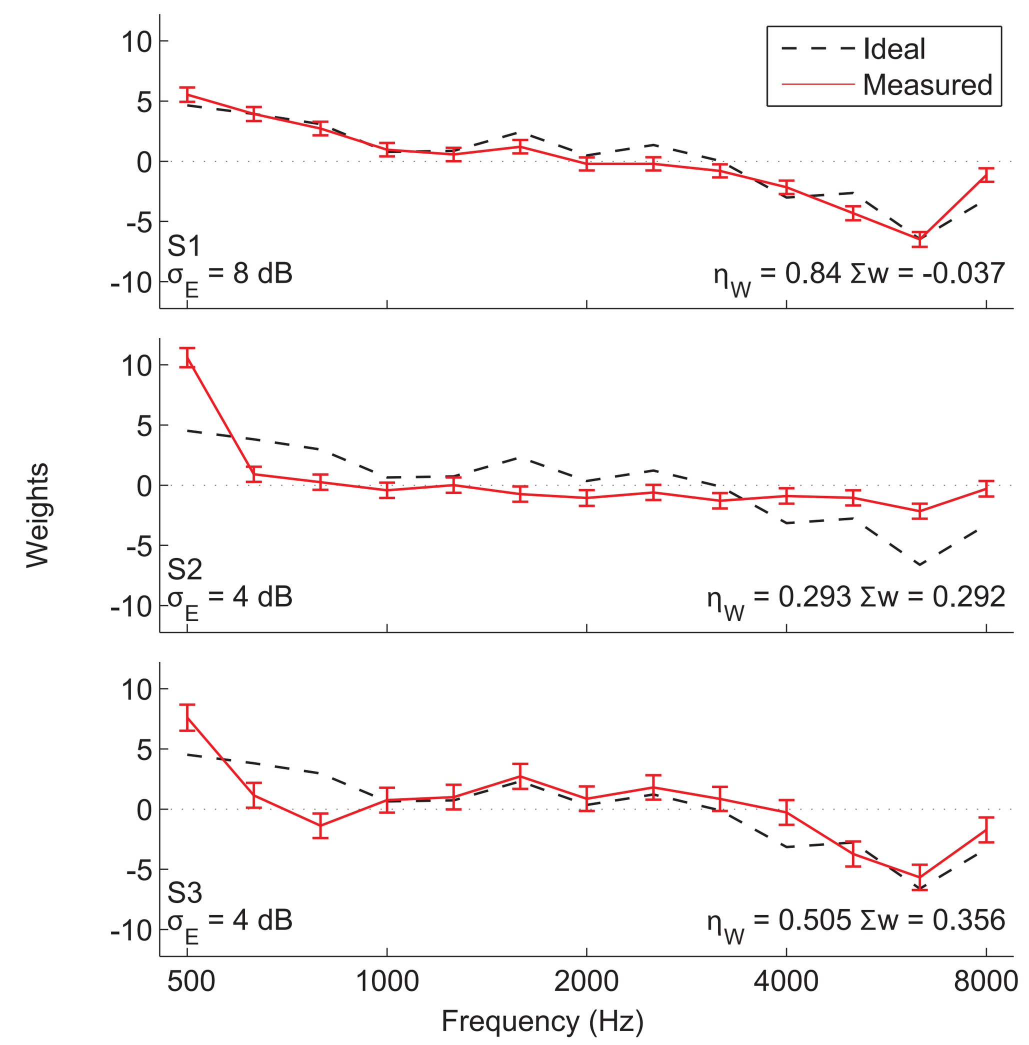

Figure 3. Shows the ideal and measured weighting functions for the three subjects. Note that σ_E was 8 dB for subject S1, but only 4 dB for subjects S2 and S3. The error bars are two standard deviations of the measured weights.

Summary

- With moderate amounts of external variability subjects can still reliably discriminate between virtual sources located ±30° from midline when listening monaurally
  - Potentially the information used for discrimination between source locations could provide a segregation cue allowing monaural listeners to obtain a spatial release from masking
- The weights reveal inefficiencies in the decision strategies of the subjects
- Discrimination performance can be predicted with a linear decision model which incorporates both weighting noise and internal noise

Acknowledgements

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