# Cross-frequency weights for loudness, pitch, and duration and their relation to speech recognition in normal-hearing and hearing-impaired listeners

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## Introduction

Sensorineural Hearing Loss (SNHL) leads to elevated thresholds and often poorer suprathreshold acuity (e.g., poorer spectral and temporal resolution). In most listeners, these effects vary in severity across frequency. *These are known peripheral effects. Are there long-term central consequences of these peripheral deficits, as well?*

<u>Prior weighting studies</u> have measured cross-frequency "weights" by having listeners make loudness judgments on a multitone complex where constituent widely-spaced frequency components are randomly and independently varied in level trial to trial.

- Studies suggest listeners with high-frequency SNHL weight high frequencies more than low frequencies (Doherty and Lutfi, 1996). Caveats:
    - Weighting differences between NH and SNHL may have been due to the higher presentation levels given to SNHL listeners (e.g., Leibold et al., 2009)
    - Suprathreshold discriminability differences across frequencies and between NH and SNHL listeners not directly corrected for in the level perturbations.
        - Could this influence weights? Because we want to examine "central" weights, it is important to ensure no peripheral influences on weights
    - Prior studies have not tested other hearing loss configurations (e.g., poorer low-frequency hearing)

**<u>Question 1:</u>** If we could correct for all peripheral influences of hearing loss in the stimuli (audibility, acuity), do SNHL listeners with uneven hearing loss across frequency consistently show alterations in the weight assigned to different frequency regions (e.g., assign greater weight to regions of better hearing)?

- <u>If so</u>, suggests weights reflect relatively fixed, generalizable alterations in the central use of cross-frequency information.
- <u>If not</u>, suggests the weights are temporary and strategic as a result of deficits present in stimulus representations.

**<u>Question 2:</u>** After compensating for differences in acuity, do the weights obtained from discrimination of simple stimuli predict relevant aspects of speech intelligibility?

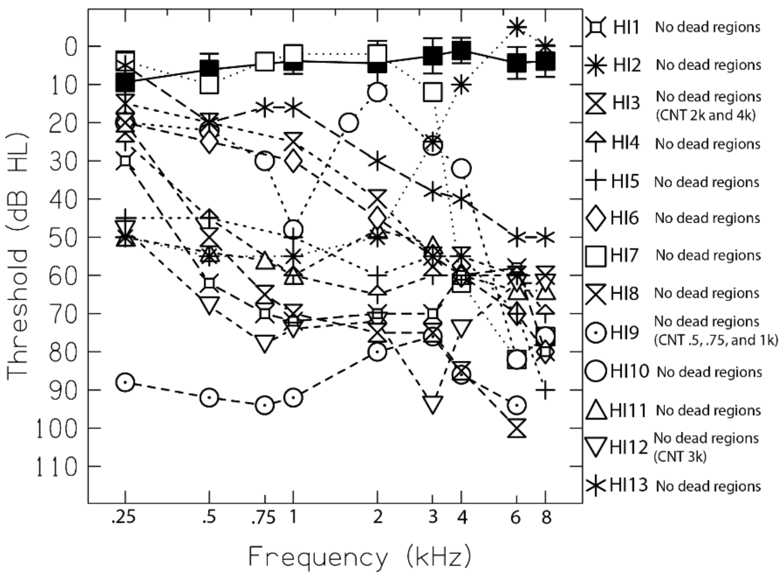
<u>In this current study</u> we tested NH and SNHL (with different hearing loss configurations) in:

- Weighting tasks (to answer Question 1)
    - For level, duration, and frequency discrimination judgments
    - Perturbation ranges based on measured discriminability of the relevant features at each frequency
    - Tested effect of overall presentaiton level
- Recognition of filtered speech (to answer Question 2)
    - Measured improvements in recognition of filtered speech with added high frequency speech bands, compared SNHL to NH, related results to cross-frequency weights

# Weighting Task Methods

## Participants

Nine young NH adults and thirteen young SNHL adults (open symbols). Audiograms for the test ear shown in Figure 1 (below).




## Stimuli

Two pure tones presented either in isolation (to measure thresholds and discriminability JNDs) or simultaneously (for weighting experiments).

In weighting experiments, trial-to-trial random perturbations in level, duration, or frequency added to the "base" tones.

Base tones:

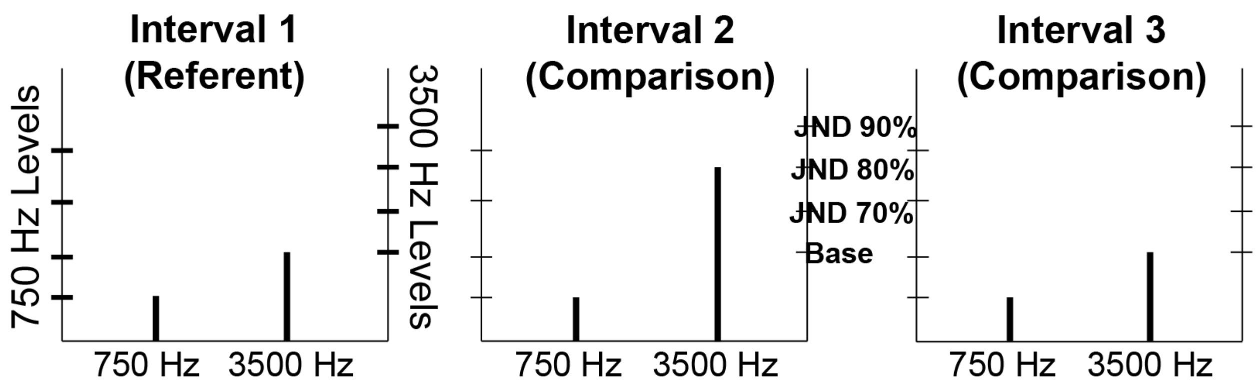
- Frequencies: 750 Hz (low) and 3500 Hz (high).
- Duration: 150 ms (5 ms ramps).
- Levels:
  - Equal SL condition- each tone (low and high frequency) set to 15 dB SL.
  - Equal SPL condition- In SNHL, tone with poorest threshold set to 15 dB SL and tone with better threshold set to equivalent SPL. In NH, both tones set to 85 dB SPL (avg of SNHL SPLs).

## Tasks

Over 6-8, two-hour sessions:

- Quiet thresholds measured for the two base tone frequencies in isolation
- Discriminability just-noticeable differences (JNDs) measured for discrimination of level, duration and frequency changes for each base tone in isolation in each base level condition (Equal SL and Equal SPL). JNDs corresponding 70,80,90% correct determined.
- Weighting of two-tone complexes using a referent discrimination task (Figure 2 below)

- Three intervals: 1st is referent containing the base stimuli. One tone in either 2nd or 3rd intervals incremented in level, duration, or frequency. Increment amount randomly selected from 70, 80, 90% correct JNDs. Listener selects interval 2 or 3.




- Also tested the same listeners in a more standard two-interval discrimination task (e.g., Doherty and Lutfi, 1996) in which the levels of both tones in both intervals randomly selected based on the discrete JND values or from a Gaussian distribution with the same Mean and SD (continuous selection).
    - Results showed consistent weights for this task and the referent discrimination task, regardless of whether levels were selected discretely or continuously.
    - All subsequent results will show referent discrimination task results only.

**Calculation of Weights**

Subject responses (which interval contained louder, longer, higher-pitched sound) regressed onto level, duration, or frequency differences between two test intervals at each frequency on each trial. Logistic regression slopes = weights at each frequency.

Weights at each frequency are normalized to sum to 1. *All results will show normalized weight at low frequency* (since there are only two frequencies, this represents all information)

**Weighting Task Results**

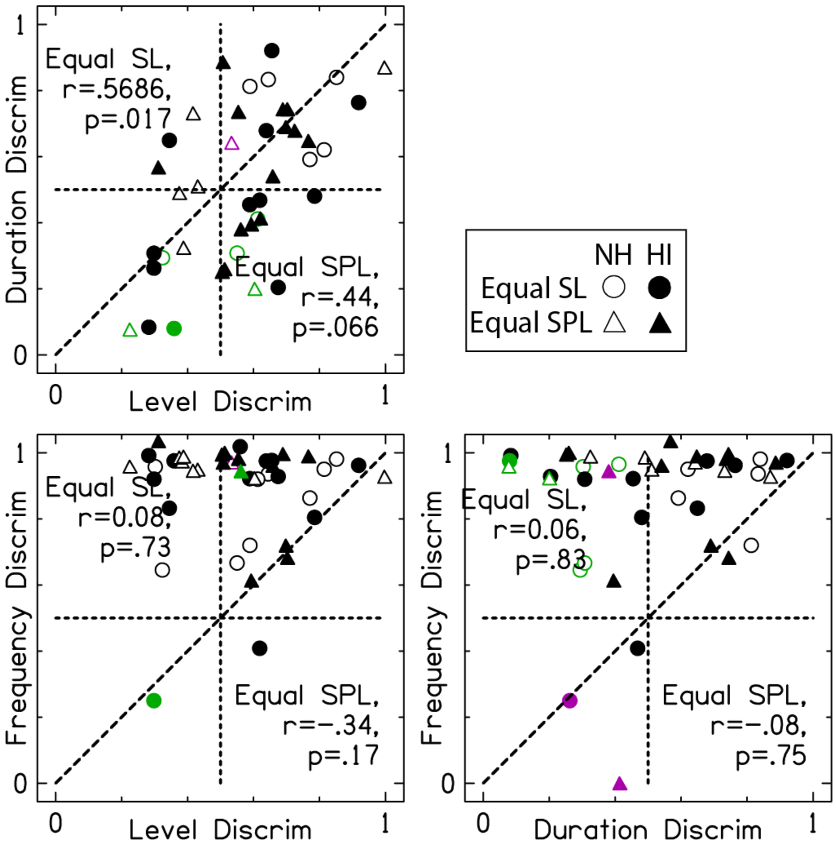
**Effect of Stimulus Dimension on Weights (Level, Duration, and Frequency weights)**

Figure 3 (below): Individual subject weight comparisons for each stimulus dimension.

*Black symbols* = weights significant in both dimensions.

*Green symbols* = weights not significant for dimension on ordinate but significant for those on abscissa.

*Magenta symbols* = weights not significant for abscissa but significant for ordinate.




Level and Duration weights (top panel, black symbols only) are significantly correlated in Equal SL condition, but not Equal SPL condition.

Frequency weights are not correlated with either Level or Duration weights (bottom two panels).

*Thus, weights are consistent across only two stimulus dimensions. Lack of relationships in other conditions may be because:*

- *Frequency weights may always be low-frequency dominated due to standard pitch perception mechanisms, which washes out any individual variability in weights.*
- *The high presentation levels in the Equal SPL condition may shift weights more to high frequencies (Leibold et al., 2009), washing out other influences on weights.*

**<u>Effects of SNHL Asymmetry on Weights with corrections for Audibility and Acuity</u>**

Do SNHL listeners show altered cross-frequency weights as a result of uneven hearing loss across frequency despite corrections for SNHL-related deficits (audibility and acuity) in the stimuli? (If so, would reflect long-term central influences of these deficits).

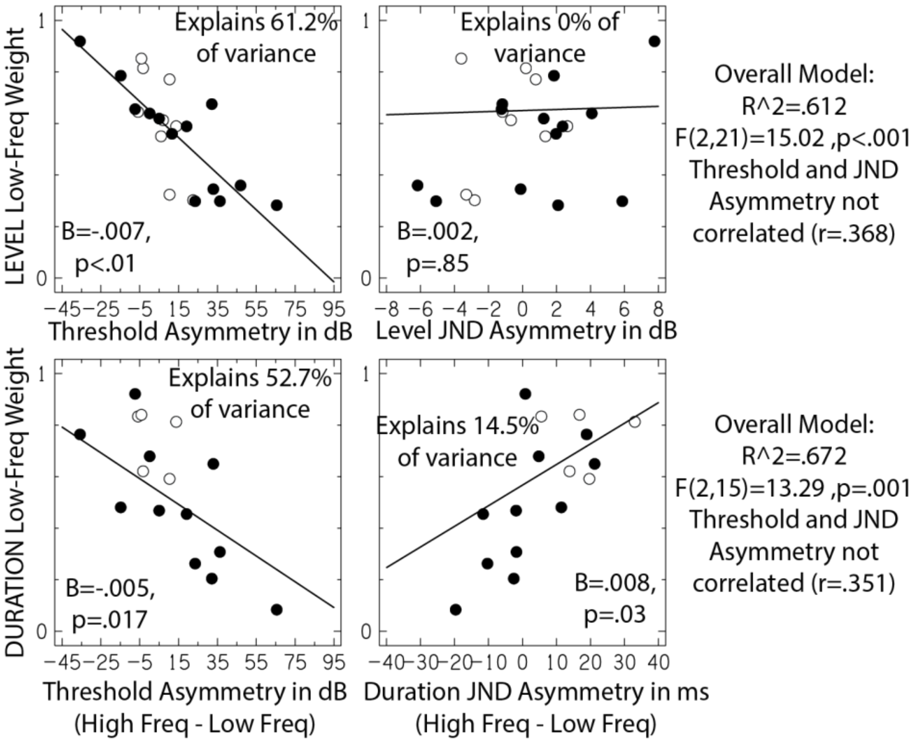
<u>Data Analysis:</u> Hierarchichal regressions which regressed weights in each stimulus dimension and level condition onto the following predictors:

<u>1. Threshold asymmetry</u> (High freq threshold - Low Freq threshold)

<u>2. JND asymmetry</u> for the relevant stimulus dimension (High freq JND - Low freq JND).

*Only models for Equal SL Level and Duration weights were significant. These are shown below in Figure 4.*

Figure 4: Results of the regression models for Equal SL Level weights (top row) and Duration weights (Bottom row). Open symbols = NH; Filled symbols = HI. First column shows threshold asymmetry predictor, second column JND asymmetry predictor. Coefficients and variance explained are printed in each panel. Overall model statistics are printed to the right of each row.




- For Equal SL Level and Duration weights, listeners with more uneven hearing loss put more weight on the frequency with poorer thresholds.
- For Equal SL Duration weights, listeners with greater asymmetry in discriminability put greater weight on the frequency with better discriminability JNDs.

*Even though SNHL asymmetry predicted these weights, the fact that threshold and discriminability JNDs predicted Duration weights in opposite directions argues against a general SNHL-related alteration of weights.*

## Recognition of Filtered Speech Methods and Results

### Participants and Procedures

All nine young NH and 10 young HI listeners from the weighting experiment participated.

Participants identified consonants in a set of 57 nonsense vowel-consonant and consonant-vowel syllables

Conditions:

- Stimuli lowpass filtered at 3k or 5.6k
- Stimuli presented in Quiet or in Noise (steady, speech-shaped)

Individualized NAL-RP gain applied to stimuli for HI

Pre-gain levels = 70 dB SPL; SNR= 5 dB in Noise condition

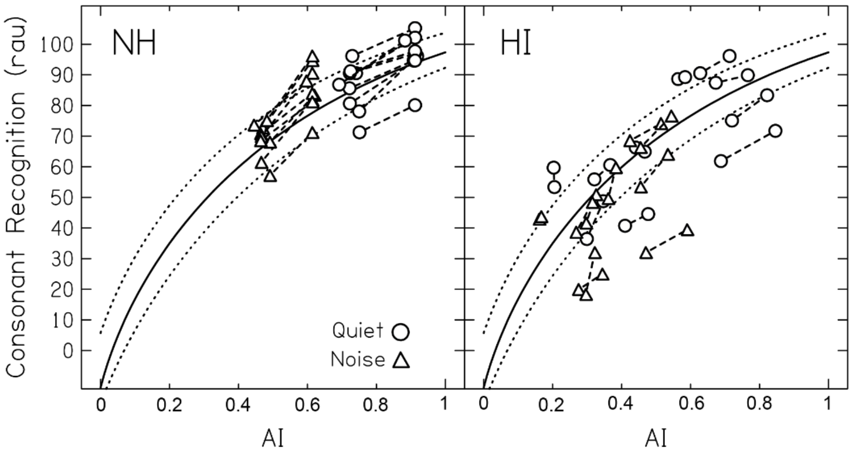
For each listener and each condition, an Articulation Index (AI) score calculated based on:

- Long-term audibility in frequency bands (based on thresholds and stimulus levels in each band)
- Relative importance of those bands for intelligibility for these materials

All percent correct scores were converted to rationalized arcsine units (rau) (Studebaker, 1985).

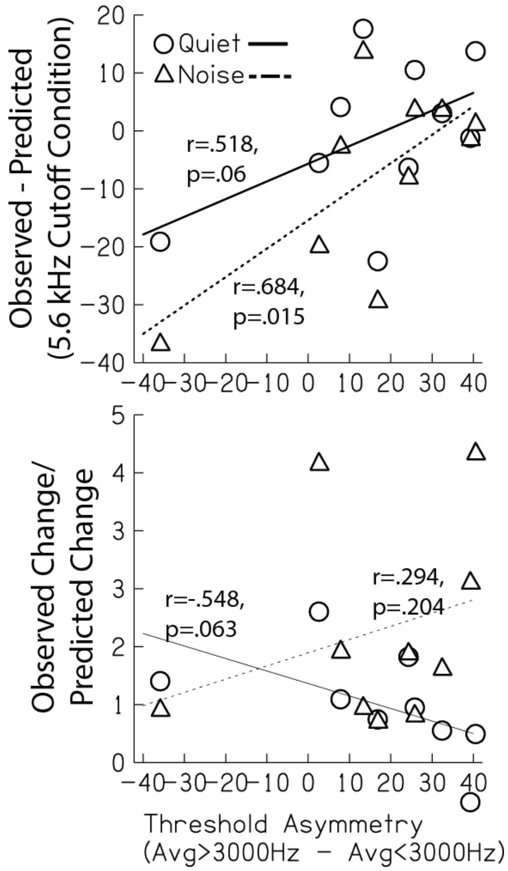
## Results

Figure 5 (below): The relationship between the AI and consonant recognition for NH (left panel) and SNHL (right panel) listeners. Connected symbols show the change in AI and recognition within a listener with a 3k to 5.6k bandwidth. The curve shows the predicted AI-recognition relationship based on previous normative data for these materials (solid curve= mean, dashed curve= +/- 2 SDs).




***Were speech recognition scores and improvements in speech scores with bandwidth related to hearing loss asymmetry in HI listeners?***

Figure 6 (below): Shows the relationship between threshold asymmetry and speech recognition (compared to AI predictions). The top panel shows observed-predicted speech recognition scores in the widest bandwidth condition. The bottom panel shows observed change in speech recognition scores from the 3k to 5.6 kHz condition/predicted change.




- Speech recognition (top panel) was poorer compared to predicted for listeners with poorer low compared to high hearing (statistically signif in Noise condition)
- Improvment in recogntion with added high frequency speech information relative to predicted was unrelated to threshold asymmetry.

*Overall, recognition performance relative to predicted (but not improvement in recognition with added bandwidth) was correlated with threshold asymmetry in SNHL listeners.*

Can filtered speech recognition results be explained by weights?

**Regression models conducted with HI data:**

The table below shows the results of two regression models:

1. Dependent variable: change in speech recognition from 3 to 5.6k cutoff frequencies/predicted change
2. Dependent variable: recognition in the widest bandwidth condition.

The predictors in each of these models were:

1) relative weights for Level (which had highest number of subjects with significant weights) in the Equal SL condition (which more closely mimics how speech levels are set than the Equal SPL condition)

2) an estimate of suprathreshold acuity from the JND measures, given that the speech experiment cannot correct for suprathreshold acuity deficits.

| Dependent Variable | Predictor | B (coefficient) | P value |
|---|---|---|---|
| Improvement in Speech Recognition in Noise (change in rau from 3k to 5.6k cutoff/predicted change) | Relative low-freq weights in Equal SL Level condition | -.318 | .889 |
| | High-freq JND for Level discrim | -.113 | .475 |
| Speech Recognition in Noise with 5.6k cutoff frequency | Relative low-freq weights in Equal SL Level condition | -7.836 | .735 |
| | Avg of High and Low Freq JND for Level discrim | -2.442 | .065 |

**Result:** *Neither relative weights nor JNDs significantly explained variance in improvements in speech recognition with added bandwidth or speech recognition in the widest bandwidth condition.*

## Conclusions

**Question 1: Were cross-frequency weights driven by asymmetry in SNHL across frequency even after correcting for audibility and suprathreshold acuity deficits in the stimulus?**

Yes:

- Threshold asymmetries significantly predicted weights in the Equal SL Level and Duration condition
- Discriminability JND asymmetries significantly predicted weights in the Equal SL Duration condition

**However,** the direction of the relationships between duration weights vs. threshold asymmetries or vs. JND asymmetries was opposite

- We had assumed the co-occurence of poor thresholds and discriminability would result in altered weights.

*Suggests changes in cross-frequency weights may not be due to effects of hearing loss per se.*

Those relationships and weights in general were related for Level and Duration discrimination in the Equal SL condition only.

*The lack of relationship with Frequency weights and weights in the Equal SPL conditions may have been due to other factors influencing weights and washing out individual differences in these conditions*

**Question 2: Do cross-frequency weights with pure-tone stimuli correlate with the use of frequency information for speech recognition (or speech recognition generally)?**

No. The use of high-frequency speech information and recognition of filtered speech was not related to relative cross-frequency weights derived from a pure-tone task.

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**References:**

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Leibold, L.J., Tan, H., and Jesteadt, W. (2009). "Spectral weights for sample discrimination as a function of overall level," JASA, 125, 339-346.