Annoyance Perception for Hearing-Impaired Listeners: A Revisit

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Introduction

Hearing-impaired listeners (HI) who utilize hearing aids often report certain sounds such as paper rustling, running water, and keys clanking as highly annoying, whereas, normal-hearing (NH) individuals are adept at ignoring or blocking out these sounds. A common approach to address these annoying sounds in hearing aid (HA) users is to reduce high frequency gain. While this approach may mitigate the complaint, it can reduce audibility for speech which often creates speech understanding difficulties and increased fatigue, particularly in noisy environments. A more efficient approach in managing sound annoyance is to identify the properties of sounds that drive annoyance perception in HI listeners and then design an algorithm to selectively reduce it. Efficient management of sound annoyance may lead HA users to being successful with their HAs.

There are many different properties of a sound that can drive annoyance perception such as loudness, sharpness, roughness, as well as, combinations of attributes. Vishnubhotla and colleagues, over the past few years, have started investigating the similarities and differences in annoyance perception between NH and HI listeners. Using real-world recordings, Vishnubhotla, et al, (2012) showed a large variability of annoyance ratings across listeners, indicating that annoyance is different across people. However, the use of real-world sounds may have contributed toward this observed large variability, possibly due to the semantic and subjective associations with presented sounds that may have influenced the study ratings.

The first objective of our experiment was to determine which acoustic properties of a sound drive or dominate the perception of annoyance in HI listeners. To do so, we used synthesized/artificial stimuli as opposed to real-world recordings in order to eliminate the semantic meanings associated with real-world sounds. A variety of acoustic parameters known to affect sensory annoyance were systematically adjusted and presented to subjects.

Methods

Participants

9 listeners with bilateral hearing loss

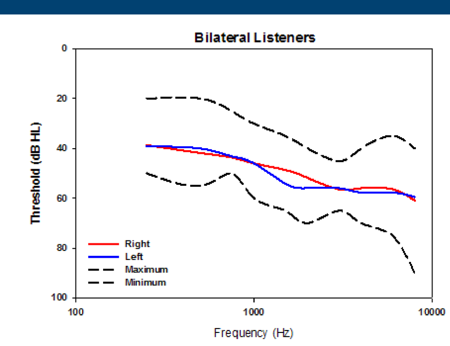
- Age Range = 55—81 years, Average = 72 years

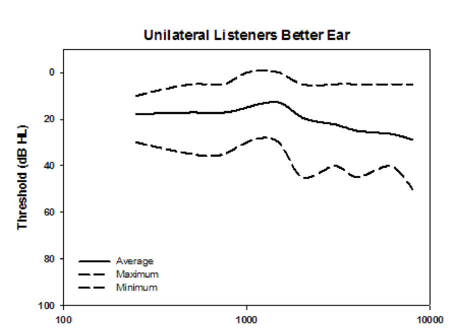
7 listeners with unilateral hearing loss

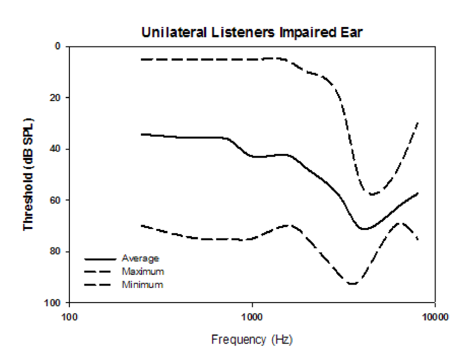
- Age Range = 31—69, Average = 55 years

5 listeners with normal hearing

- Age Range = 31—58 years, Average = 41 years







Stimuli

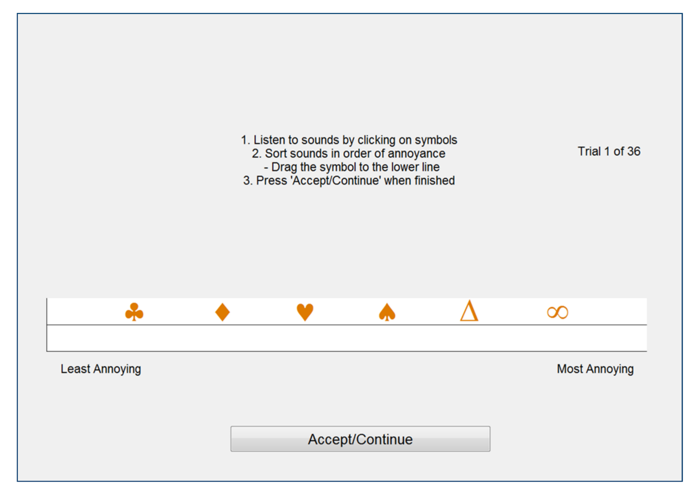
◊ Synthetic complex sounds
◊ 2 seconds in length, sampling rate of 44100 Hz
◊ Table 1 shows the unique parameters for each stimulus, there is a broadband and narrow band version of each stimulus
  - ◊ Exception there was not a narrowband version of the multi-band stimuli
◊ High frequency cutoff for broadband stimuli was 10000Hz

Cutoff /Center Frequency	Modulation Type	Number of Bands	Modulation Frequency	Modulation Depth
500, 1000, 2500, 5000	Sinusoidal	0	0	0
500, 1000, 2500, 5000	Sinusoidal	1	32	.5, 1
500, 1000, 2500, 5000	Sinusoidal	1	64	.5, 1
500, 1000, 2500, 5000	Random	1	2	1
500, 1000, 2500, 5000	Random	1	8	1
500, 1000, 2500, 5000	Random	1	32	1
500, 1000, 2500, 5000*	Random	3	32, 8, 2 (one for each band)	1, 1, 1 (one for each band)

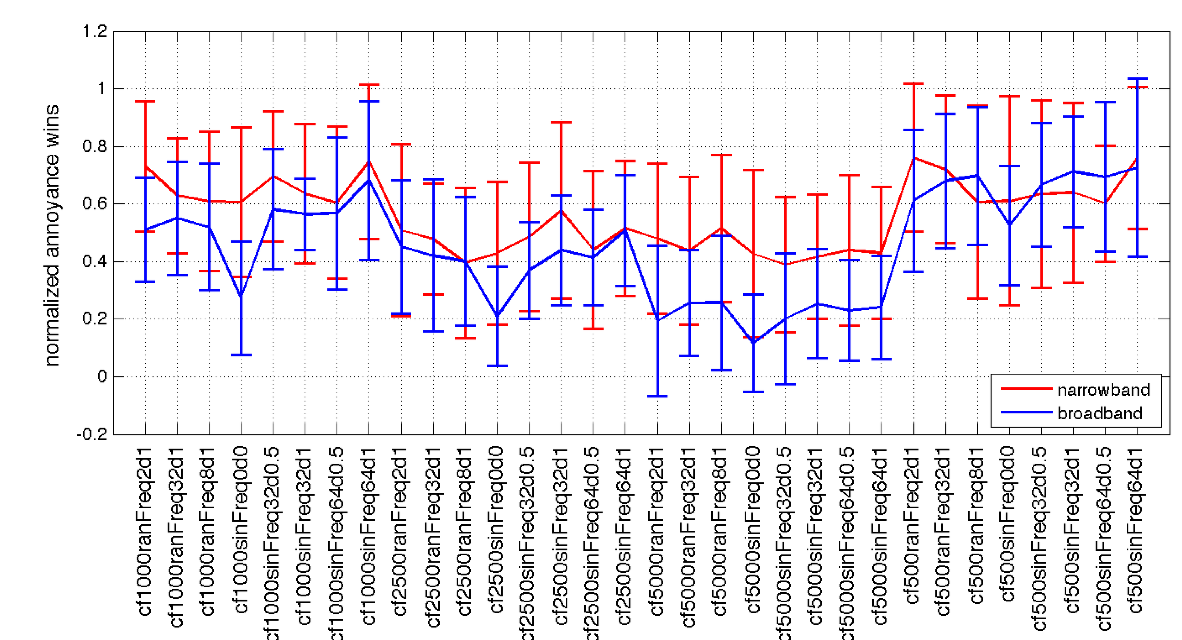
Annoyance Ordering Task

Method

◊ Total of 72 unique stimuli, presented at 85 dB SPL
◊ 6 stimuli were presented at a time
◊ Each stimulus was presented 3 times within a different set of stimuli
◊ BHL participants were asked to order the stimuli in order of their perceived annoyance
◊ Stimuli were 2 seconds in length
◊ Presented over headphones to the left ear in a sound treated room



Results



Trends from the data

◊ Narrowband stimuli generally more annoying than broadband stimuli
◊ Stimuli with 5000 Hz edge frequency (broadband) or center frequency (narrowband) were less annoying than other stimuli
◊ The largest effect of on annoyance for modulation depth was going from no modulation to a modulation depth of one
◊ Based on these results, the stimuli with a 5000 Hz edge or center frequency or with a modulation depth of .5 were excluded from the magnitude estimation task
◊ The reference stimulus for the magnitude estimation task was chosen as a broadband stimulus with a 500 Hz edge frequency

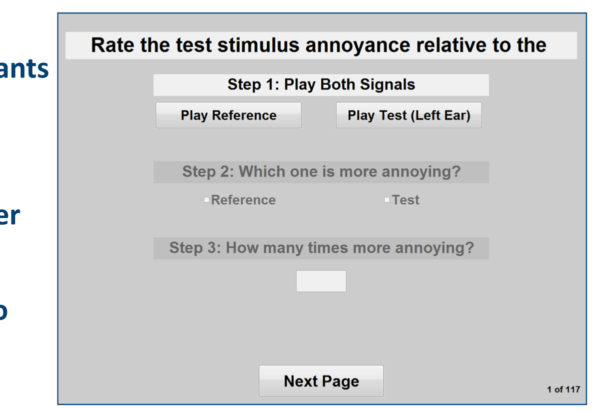
Annoyance Magnitude Estimation

Method

◊ Subset of 39 stimuli were chosen from the Ordering Task
◊ All stimuli presented via insert earphones (ER-3A)
◊ A training task was used to familiarize the listeners with the stimuli prior to the magnitude estimation task
◊ Participants indicated which stimulus was more annoying and then provided a number to indicate "how much more annoying the stimulus was"
  - ∗ E.g., the stimulus is two times as annoying as the reference stimulus

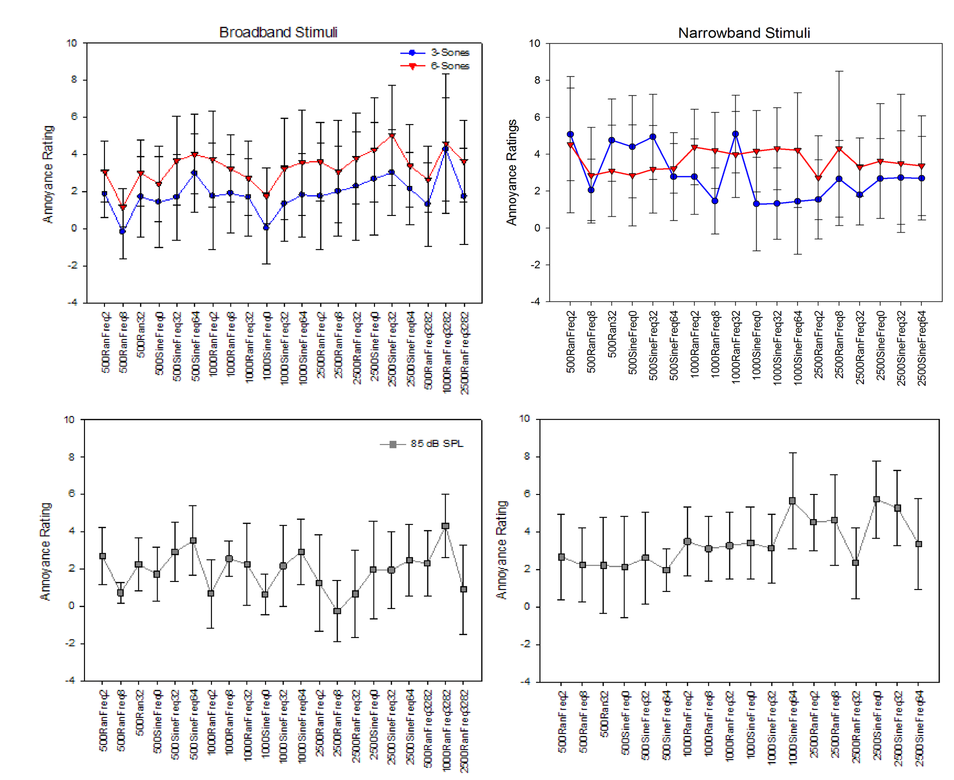
Method & Results

◊ The reference stimulus was a broadband stimulus with an edge frequency of 500 Hz presented at 85 dB SPL on every trial
◊ Each test stimulus was presented at iso-level condition of 85 dB SPL, iso-loudness conditions 3 & 6 sones
◊ A total of 3 repetitions per stimulus
◊ Both BHL (presented to Left Ear) and UHL participants completed this task
◊ UHL completed two conditions
  - ◊ Reference was presented to their good/better ear and test was presented to their poor ear
  - ◊ Reference and test stimuli were presented to their good ear



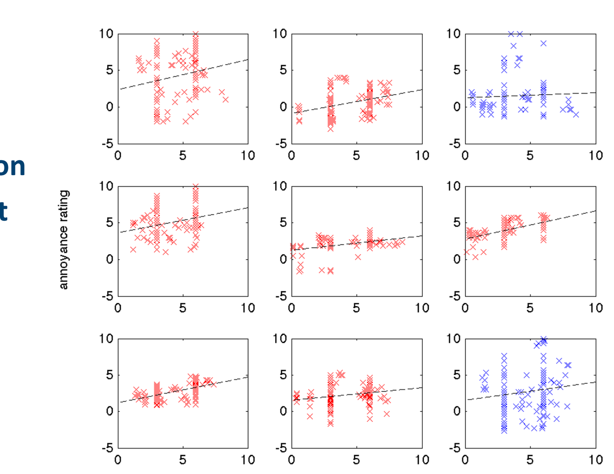
Results

Listeners with Bilateral Hearing Loss



◊ Three-way ANOVA with bandwidth (Broadband/Narrowband), edge/center frequency (500, 1000, 2500Hz) and Level (3-Sones, 6-Sones, 85-dB SPL) as factors
  - ◊ Stimuli presented at 6-sones were more annoying than those presented at 3-sones or 85 dB SPL
    - ◊ Mean loudness of 85 dB SPL broadband stimuli was 3.8 sones
    - ◊ Mean loudness of 85 dB SPL narrowband stimuli was 4.1 sones
  - ◊ Narrowband stimuli were more annoying than broadband stimuli
  - ◊ Stimuli with a edge/center frequency of 1000 or 2500 Hz were more annoying than those with a 500 Hz edge/center frequency

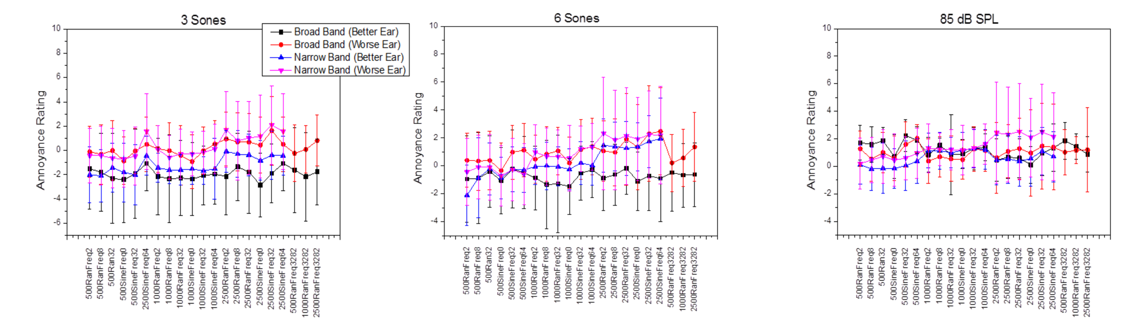
◊ Individual data showing annoyance as a function of loudness, for 6 of 8 BHL there is a significant positive correlation (plots in RED) between annoyance and loudness.

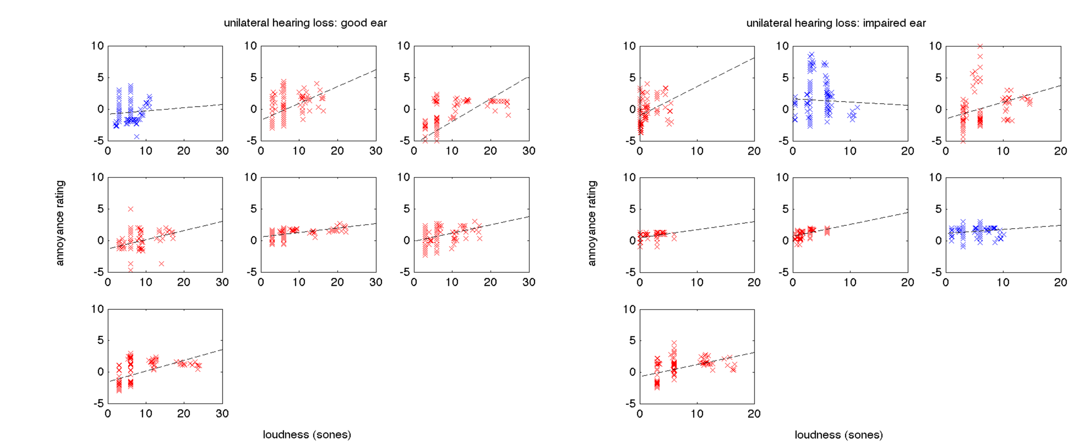


Listeners with Unilateral Hearing Loss

◊ Three way ANOVA, ear (better, worse), level (3-sones, 6-sones, 85 dBSPL), bandwidth (broadband, narrowband) as factors
  - ◊ Narrowband stimuli were rated more annoying than broadband stimuli in both the better and worse ears
  - ◊ For stimuli presented at 3-sones and 6-sones, there were significant differences in annoyance ratings between the better ear and the worse ear
    - ◊ Stimuli were rated as more annoying when presented to the worse ear than when presented to the better ear

Results

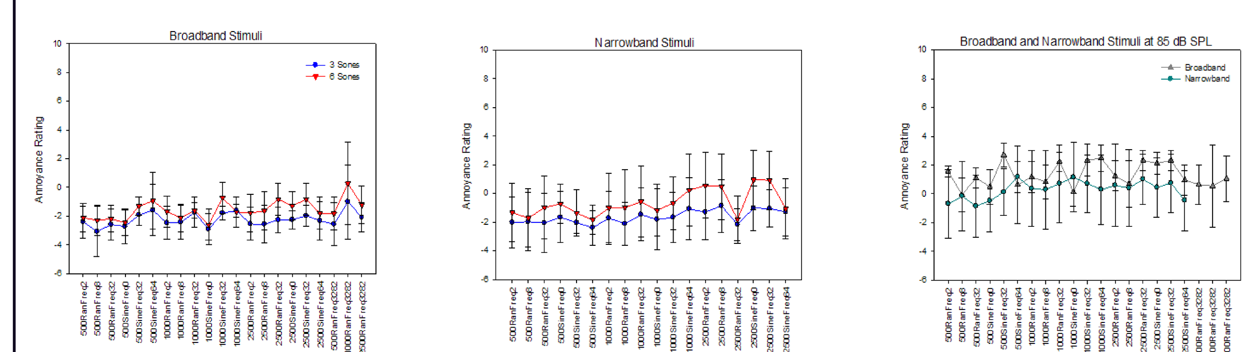




◊ Individual data showing annoyance as a function of loudness, for most UHL (better & worse ear) there is a significant positive correlation (plots in RED) between annoyance and loudness.
  - ◊ Increase in loudness lead to an increase in annoyance.

Listeners with Normal Hearing

◊ The reference stimulus was generally rated more annoying than the test stimuli, different from the BHL group
◊ Similar to the hearing-impaired listeners narrowband stimuli were rated more annoying than the broadband stimuli, but not to the same degree
◊ For ALL (5) NH listeners as the loudness of the stimulus increased the annoyance rating also increased, significant positive correlations between annoyance and loudness



Conclusions

◊ Loudness is the number one driver of annoyance, louder stimuli are rated more annoying
◊ Narrowband stimuli, specifically mid-high frequency stimuli, are perceived as more annoying than broadband stimuli
◊ Normal-hearing listeners show a different pattern of annoyance than bilateral hearing-impaired listeners, in that the reference was more annoying than the test stimuli in more instances and rated stimuli generally less annoying than the listeners with hearing loss
◊ The better ear for the unilateral listeners perceived annoyance more similar to the NH listeners, whereas the impaired ear performed most like the BHL, in terms of annoyance ratings
◊ Next Steps
  - ◊ Further investigate the role of modulation type and modulation frequency on annoyance perception for the listeners in this study
  - ◊ Investigate if any current annoyance model can account for the hearing-impaired data
    - ◊ Develop an annoyance model for hearing-impaired listeners

References

Vishnubhotla, S., Xiao, J., Xu, B., McKinney, M. and Zhang, T. (2012). Annoyance perception of environmental noises by hearing impaired listeners. Journal of the Acoustical Society of America, 131(4), 3536

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