# Objective measures of auditory stream segregation in normal-hearing and hearing-impaired listeners using multi-tonal complexes

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## Introduction

Listeners with hearing loss often complain of difficulty understanding speech in complex and noisy environments. This process requires the ability to segregate a meaningful signal from an unwanted background. In addition to a distorted representation of the acoustic signal, poor sound segregation abilities could also lead to difficulty understanding speech in the presence of interfering sounds. The mechanisms which underlie the ability to segregate one sound from another currently are not well understood, but peripheral and central processes are probably involved (Bregman, 1990; Darwin and Carlyon, 1995). Listeners with hearing loss have been shown to have changes to both peripheral and central auditory processing, and therefore might also experience difficulties with stream segregation (Arehart *et al*., 1997; Mackersie *et al*., 2001, Kidd *et al*., 2001). The goal of the following study is to evaluate the effects of hearing loss on broadband auditory streaming using an objective paradigm.

Previous studies have established some link between hearing loss and performance on auditory stream segregation, with little consensus among studies regarding the sources of those differences (Rose and Moore, 1997; Grimault *et al*., 2001; Stainsby *et al*., 2004). These studies evaluated auditory stream segregation abilities of listeners using either 1000-Hz tones or harmonic complexes, and therefore the tasks contained both place and temporal cues. Additionally, most previous measurements of auditory streaming ability have adopted a subjective paradigm in which the stimulus is constantly changing and listeners press a button when they experience a perceptual change in the stimuli (Rose and Moore, 1997; Grimault *et al*., 2001; Mackersie *et al*., 2001). This method of measuring auditory streaming contains obvious drawbacks, such as observer bias, and response times that might vary across listeners. A more recent method for measuring auditory stream segregation was developed by Cusack and Roberts (1999). This method uses a paradigm in which detecting a temporal change would be more difficult if two sounds were perceived in different auditory streams. Using the approach of Cusack and Roberts (1999), this experiment will evaluate stream segregation abilities using broadband *inharmonic* stimuli that have no consistent temporal pattern across channels and also will stimulate a greater portion of the basilar membrane. Performance on this task will be compared between normal hearing and hearing impaired listeners.

## Methods

### SUBJECTS

- Six Normal-Hearing listeners (NH) ranging in age from 28 to 64 years, mean of 49 yrs
- Five Hearing-Impaired listeners (HI) ranging in age from 39 to 65 years, mean of 53 yrs.

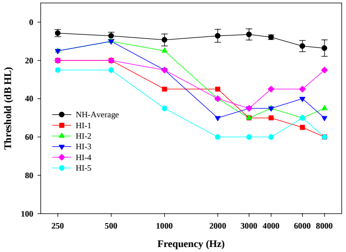

Figure 1: Mean audiogram for NH listeners and individual audiograms for HI listeners. Error bars represent the standard error of the mean across six normally hearing subjects.

## Methods Cont.

### STIMULI

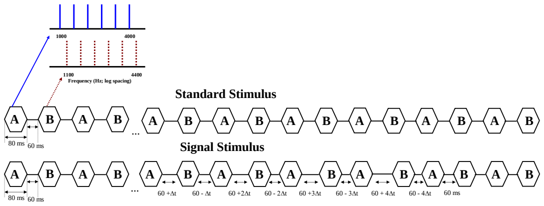

Figure 2: Schematic of the A_B_ paradigm to be used in this stream segregation task. Additionally, the spectrum of the A and B complexes are shown (for the 1100-Hz B stimulus).

- Each stimulus was an alternating sequence A_B_A_B_A_B_… in which A & B represent multi-tonal complexes and _ represents a silent interval
- A & B stimuli were the sum of six equal-amplitude sinusoids (80 dB SPL per component) spaced equidistantly on a log scale (frequency ratio 1.32)
- Frequencies of the components of the A stimulus always ranged between 1000 and 4000 Hz
- Each component of the B stimulus is separated from each component of the A stimulus by a multiplicative factor ($\Delta f_B/f_A$) (lowest frequency in the B stimulus was 1000, 1030, 1060, 1080, 1100, 1200 or 1400 Hz)
- Phase of each individual component chosen randomly
- Duration of A & B was 80 ms including 16 ms cosine squared rise/fall times

### STANDARD SEQUENCE

- A silent interval of 60 ms followed each multi-tone stimulus (A & B)
- Each sequence was composed of 12 A_B_ cycles, leading to an overall duration of 3.36 sec
- See top panel of Fig. 2 for a schematic.

### SIGNAL SEQUENCE

- On the 7th cycle, a delay (Δt ms) was added to the 60 ms silent interval following the A stimuli (silent interval = 60 + Δt ms), thus increasing the duration of the silent interval between the A and B stimuli. Additionally, the silent interval following the B stimuli of the cycle was reduced by Δt (ms) (silent interval = 60-Δt ms).
- Over the next three cycles, the delay was progressively increased by an additional Δt, leading to a final cumulative delay of 4Δt on the tenth A_B_ cycle. For the last two cycles the silent interval reverts back to 60 ms.
- See bottom panel of Fig. 2 for a schematic.

### PROCEDURE

- 2-AFC, 2-down, 1-up tracking procedure used to estimate thresholds

## Results

- Figure 3 plots the average just detectable delay (Δt) as a function of the starting frequency of the B stimulus for each group of listeners
- Normal-hearing and hearing-impaired data are plotted as the unfilled triangles and filled circles, respectively
- Error bars represent the standard errors of the mean

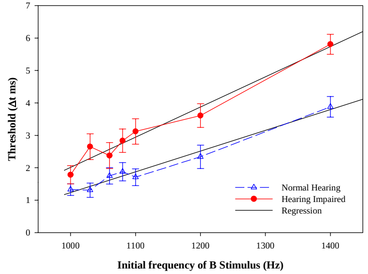

Figure 3:Thresholds for normal-hearing and hearing-impaired listeners, plotted as a function of the initial frequency of the B stimulus.

- Figure 3 shows that sensitivity to temporal changes across frequencies decreases with increasing frequency separation between the A and B stimuli for both groups of listeners.
- In general, listeners with hearing loss tend to have poorer sensitivity than listeners with normal hearing.
- The results for the hearing-impaired listeners produced a steeper overall function, indicating that performance more quickly degrades for hearing-impaired listeners as frequency separation increases.
- Figure 4 plots the data for each individual listener, hearing-impaired listeners are plotted in the left panel and normal hearing listeners in the right panel.

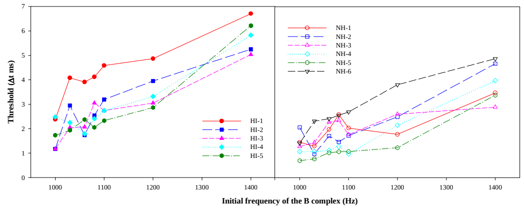

Figure 4:Individual thresholds for normal-hearing and hearing-impaired listeners, plotted as a function of the starting frequency of the B stimulus.

### STATISTICS

Factors:

- Hearing loss
- Initial frequency of the B stimulus

Repeated measures ANOVA indicates significant effects of:

- Main effect of the initial frequency of the B stimulus [F(6,54) = 63.36, $p < .001$]

  As the B stimulus becomes further in frequency from the A stimulus, performance degrades.

- Main effect of the group [F(1,9) = 9.86, $p < .015$]

  Listeners with hearing loss have higher thresholds than listeners with normal hearing.

- Two-way interaction of hearing and initial frequency of the B stimulus, [F(6,54) = 3.44, $p < .001$]

  Indicates that the slope of the function between the two groups of listeners differ: Sensitivity of hearing-impaired listeners degrades more quickly with increasing frequency separation than for normal-hearing listeners.

## Discussion

In general, as the B stimulus becomes further in frequency from the A stimulus, the ability to detect a temporal change across frequency becomes more difficult. This result is present for both groups, suggesting that both hearing-impaired and normal-hearing listeners have more difficulty detecting a temporal change between stimuli as the frequency separation between those stimuli increases. This finding is consistent with the results of Cusack and Roberts (1999) who showed that the threshold for a temporal change was larger when two stimuli were perceptually distinct. Their argument predicts that an increase in frequency separation between the A and B stimuli would lead to more segregation and therefore a longer gap duration would be needed for detection, and leading to higher thresholds at the larger frequency separations.

While performance degraded with increasing frequency separation for both groups of listeners, normal-hearing listeners had overall better sensitivity than hearing-impaired listeners in detecting the temporal change. Interestingly, the performance of listeners with hearing loss degraded more quickly with increasing frequency separation than performance of listeners with normal hearing. Thresholds are most similar between the two groups when the A and B stimuli have the same frequencies. Thresholds are the most different between the two groups when the A and B stimuli are most different. Taken together, these results indicate temporal processing deficits in listeners with hearing loss (evident in the main effect revealed by the ANOVA), but the temporal processing deficit becomes more evident when temporal comparisons across frequency become necessary (note the significant interaction).

Because thresholds are similar at 1000 Hz (the frequency at which A and B stimuli have the same frequencies), within-channel comparisons of temporal changes are unaffected by hearing loss as applied to this task. Once the A and B stimuli do not overlap entirely, then performance degrades in the impaired ear, indicating that listeners with hearing loss do experience difficulties using temporal cues. However, in these conditions, listeners are required to make temporal comparisons across frequency. Recall that Cusack and Roberts (1999) argue that when stimuli are perceived as being more similar (i.e., in a single auditory stream), the thresholds for detecting a temporal change should be lower than when the stimuli are perceived as being different (e.g., in two auditory streams). Applying their argument to this experiment then, if listeners with hearing loss experienced less segregation at larger frequency separations (e.g., due to reduced frequency selectivity), their thresholds are predicted to be *lower* than for the normal-hearing listeners. Therefore, the higher thresholds obtained from hearing-impaired listeners probably indicate a central contribution to this streaming task. Because thresholds are poor for hearing-impaired listeners at the large frequency separations, these listeners are having difficulty integrating across frequency. These difficulties in detecting temporal changes across frequency are likely to lead to difficulties segregating speech sounds in complex acoustic environments.

## Conclusions

- Differences between normal-hearing and hearing-impaired listeners indicate that hearing loss may degrade ones performance on an obligatory stream segregation task.
- Sensitivity to temporal changes across frequency becomes poorer more rapidly for listeners with hearing loss than listeners with normal hearing, indicating that hearing loss impairs the ability to make across frequency temporal comparisons.
- The difference between the groups of listeners is most likely not due to differences in frequency selectivity but may be related to changes in the central auditory processes responsible for across frequency temporal comparisons.

## References

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