Hearing Loss and Informational Masking

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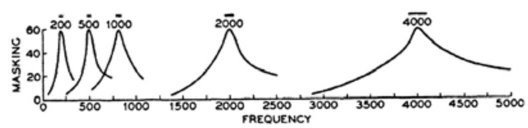
- Introduction to Informational Masking
- Informational Masking with Speech
- Release from Informational masking
- Hearing Impairment and Release from Informational Masking
- A Conceptual Model with Implications for Hearing Impaired Listeners and Future Work

The Ear as a Frequency Analyzer

Using brass spheres of various volumes to focus his auditory perception, Hermann von Helmholtz (1821-1894) was able to determine the spectral composition of a wide variety of musical sounds.

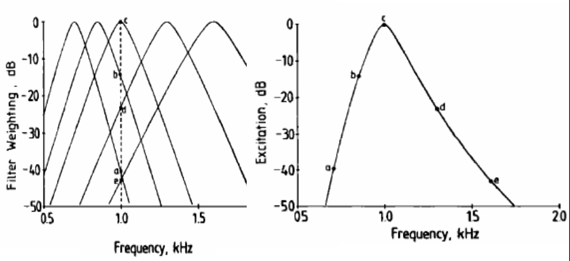
This experience and his physiological investigations convinced him that the ear performs a spectral decomposition of the incoming sounds.

Fletcher (1940) proposed a quantitative model based on the idea of peripheral filtering.



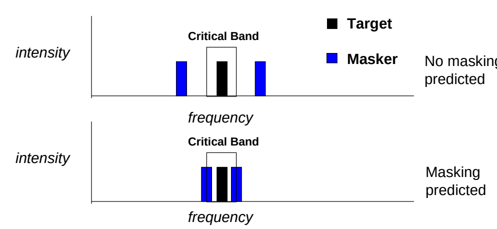
Fletcher (1940) "Auditory patterns" Reviews of Modern Physics, 12 (Figure 12)

Most modern theories of auditory perception still start with a bank of bandpass filters.



Moore and Glasberg (1983) "Suggested formulae for calculating critical bands and excitation patterns," JASA, 74(3) (Figure 3)

Masking the output of a band-pass filter

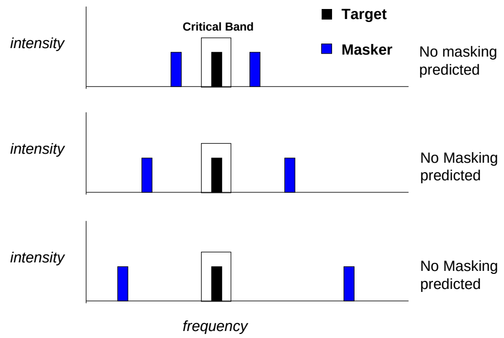


The filter-bank model of hearing implies that when a listener detects a tone of a certain frequency, the information used is essentially the output of a critical band filter.

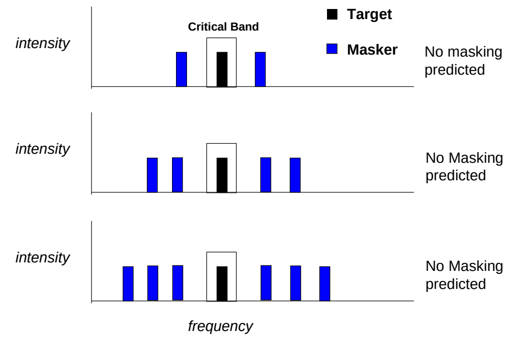
Energy falling within the critical band "masks" the target (in black).

- Note that the rectangular filter above is a cartoon of the filters shown on the previous slides

The critical band model predicts little effect of the **distance** of the maskers from the critical band



The critical band model predicts little effect of the **number** of maskers outside the critical band



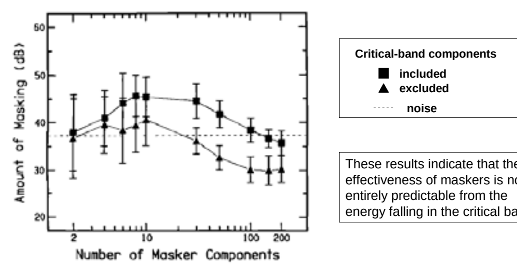
- Note that there would be some slight masking (and changes in masking) predicted in these cases due to changes in the energy falling in the "skirts" of the filter. The point is that these changes would be slight (probably only a few dB).

The simplest form of the Filter Bank model holds that masking is *entirely* predicted by the energy falling inside the critical band filter.

This is simply not correct.

Target: 60 dB, 1000 Hz tone
Maskers: multiple tones with frequencies between 300-3000 Hz or equivalent power noise

Masker frequencies drawn at random on each trial and either included or excluded frequencies near the critical band



These results indicate that the effectiveness of maskers is not entirely predictable from the energy falling in the critical band.

Neff and Callaghan (1988) "Effective properties of multicomponent simultaneous maskers under conditions of uncertainty", JASA, 83 (Figure 1)

What is Informational Masking?

Durlach et al. (2003) suggested that informational masking at a given level, L, of the auditory system is any reduction in performance that cannot be predicted on the basis of current models of signal processing at level L.

As we learn more about how information is processed by the auditory system, the domain of informational masking will decrease.

Durlach, Mason, Kidd, Arbogast, Colburn and Shinn-Cunningham (2003) "Note on Informational Masking", JASA, 113

What Do We Know About When Informational Masking Will Occur?

- Durlach et al. (2003) and Watson (2005) suggested that there are two factors that lead to informational masking:
- **Target-Masker Similarity**, which leads to confusions between the target and the masker.
- **Stimulus Uncertainty**, which leads to potential widening of the auditory filters or "holistic" listening (as opposed to "analytic" listening).
- In addition, it has been well documented that some listeners are more susceptible to informational masking than are others.

Watson (2005) "Some Comments on Informational Masking", Acta Acustica United with Acustica, 91

What Reduces Informational Masking?

- **Dissimilarity** between the target and masker (binaural, temporal or spectral)

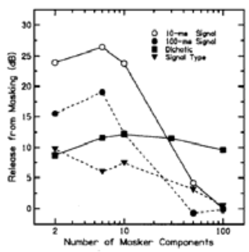
Target: 10-, 100- or 200- ms 1000-Hz tone

Masker: 200-ms multicomponent maskers with a "protected" region centered on the target frequency (1000 Hz).

Release calculated relative to masking with a 200-ms signal.

Dichotic: target 180-degrees out-of-phase; maskers diotic.

Signal-type: amplitude modulation of various types applied to the target; narrowband noise target.



Neff (1995) "Signal properties that reduce masking by simultaneous, random-frequency maskers", JASA, 98 (Figure 6)

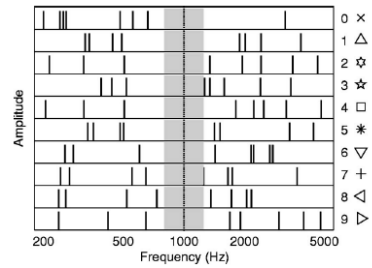
What Reduces Informational Masking?

- **Certainty** about the stimulus

Target: 1000 Hz tone.

Maskers were either **Fixed** across a block of trials or presented in **Random** order.

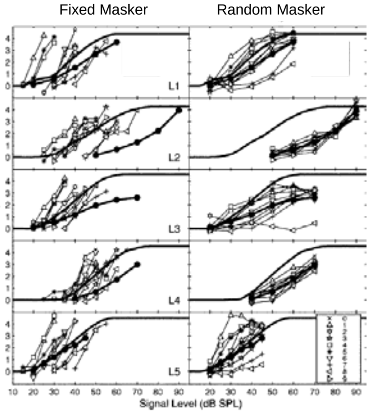
Total masker level was always 60 dB SPL.



Durlach, Mason, Gallun, Shinn-Cunningham, Colburn, and Kidd (2005) "Informational masking for simultaneous nonspeech stimuli: Psychometric functions for fixed and randomly mixed maskers", JASA, 118 (Figure 1)

Ten-component maskers with a "protected" region centered on the target frequency.

Fixed Masker | Random Masker



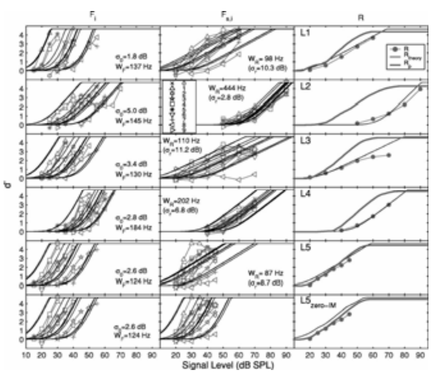
Fixed (pooled)
Random

L1 - L4: Fixed better than Random

L5: No Difference

For most listeners, certainty about the masker improved performance.

Durlach et al. (2005) Figure 2



The data were largely captured by a model best described as a single filter of adjustable width centered on the target frequency.
This model thus includes both energetic and informational components.

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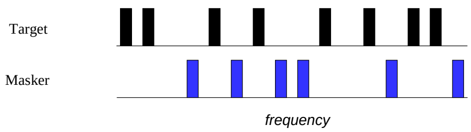
Informational Masking with Speech:
It isn't just for tones anymore…

- A number of recent studies have demonstrated substantial informational masking with speech stimuli.
- These results, along with large effects of binaural and spatial separation, have direct relevance to listening in real world environments.
- Increasingly, these studies have considered the effects of age and hearing loss as well.

Informational Masking with Speech Stimuli

To reduce the effects of peripheral or "energetic" masking, processed speech has been used. Masker energy restricted to non-target critical bands.

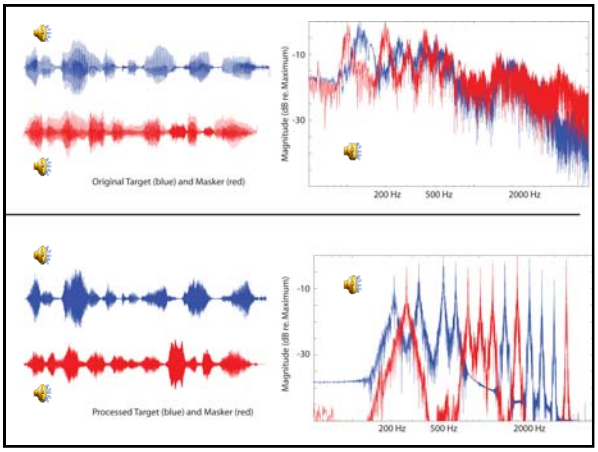


Sentences were of the form "Ready [callsign] go to [color] [number] now."

32 possible keyword combinations: 4 colors (red, white, green, blue) and 8 numbers (1 to 8). Four different male talkers and eight different callsigns.

Bolia, Nelson, Ericson, and Simpson (2000) ''A speech corpus for multitalker communications research,'' JASA 107

Arbogast, Mason and Kidd (2002) "The effect of spatial separation on informational and energetic masking of speech", JASA, 112



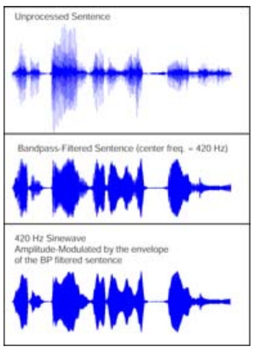
The Processing Scheme

1) Sentence passed through 15 1/3-octave bandpass filters (evenly spaced in log frequency between 215 Hz and 4891 Hz).

2) Envelope of each filter output extracted via lowpass filtering (50 Hz) and halfwave rectification.

3) Envelope used to modulate a sinusoid with a frequency identical to center frequency of bandpass filter.

4) 8 modulated sinusoids randomly selected for target. 6 of remaining 7 selected for masker.



A new set of frequencies was chosen on each trial.

How much energetic masking is there?

60 dB Speech Target

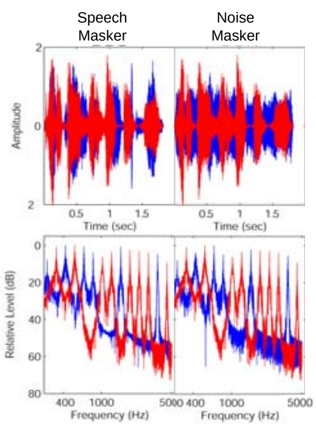
Task: Identify key words ('Blue Four')

Masker:
Different-band Speech or
Different-band Noise

Callsign 'Baron' used to identify target sentence.

Target

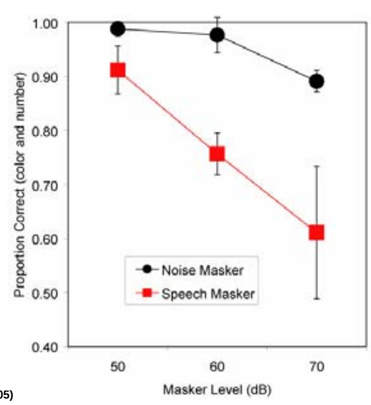
Masker



Kidd, Mason and Gallun (2005) "Combining energetic and informational masking for speech identification", JASA, 118 (Modified from Figure 1)

60 dB Speech Target
Task: Identify key words

Substantially more masking for speech than for noise masker.



Kidd, Mason and Gallun (2005) (Modified from Figure 2)

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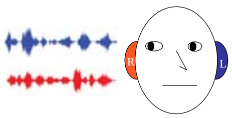
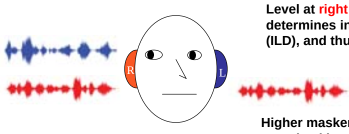
Binaural Release from Informational Masking



Monaural Target
Monaural Masker

60 dB Speech Target
Task: Identify key words ('Blue Four')

Callsign 'Baron' used to identify target sentence.

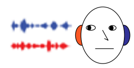


Monaural Target
Binaural Masker

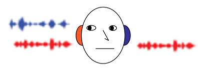
Level at right ear fixed. Level at left ear determines interaural level difference (ILD), and thus perceived location.

Higher masker level at left ear shifts perceived location away from the target.

Masker: Different-band Speech



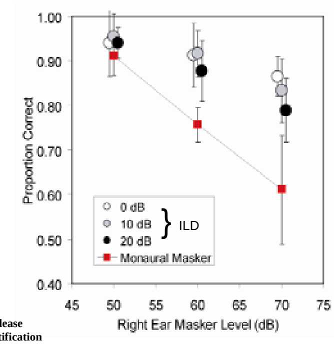
Monaural Masker



Binaural Masker

Result: ***Higher*** masker levels at the non-target ear lead to better performance!

Effect of adding a masker to the non-target ear (more masker at left ear, smaller ILD)



Gallun, Mason and Kidd (2005) "Binaural release from informational masking in a speech identification task", JASA, 118 (Adapted from Figure 3)

Binaural Release from Informational Masking

These results are representative of a growing literature indicating that for young, normal hearing listeners, real or perceived spatial separation is an extremely effective method of reducing informational masking.

Examples:

- **Carhart, Tillman, and Greetis (1969) "Release from multiple maskers: Effects of interaural time disparities", JASA, 45**
- **Freyman, Helfer, McCall, and Clifton (1999). "The role of perceived spatial separation in the unmasking of speech", JASA, 106**
- **Freyman, Balakrishnan, and Helfer (2001). "Spatial release from informational masking in speech recognition", JASA, 109**
- **Arbogast, Mason, and Kidd (2002) "The effect of spatial separation on informational and energetic masking of speech", JASA, 112**
- **Brungart and Simpson (2002) "Within-ear and across-ear interference in a cocktail-party listening task" JASA, 112**
- **Best, Ozmeral, Gallun, Sen and Shinn-Cunningham (2005) "Spatial unmasking of birdsong in human listeners: Energetic and informational factors", JASA, 118**

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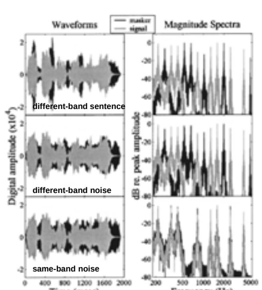
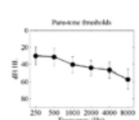
What about Hearing Impaired Listeners?

- Arbogast et al. (2002; 2005) used these same stimuli, but presented the stimuli from colocated or separate locations in an open-field environment.
- 10 normally hearing (NH) and 10 hearing impaired (HI) subjects (both aged 19-79) participated.
- Performance was measured for three different maskers: **different-band sentence, different-band noise, same-band noise.**



Arbogast et al. (2002) Figure 2



Average audiogram for HI listeners

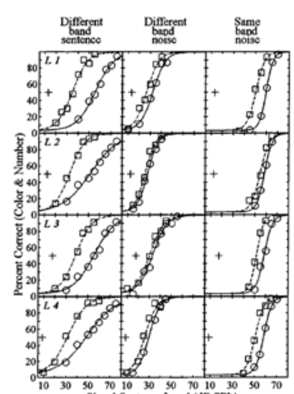
Arbogast, Mason and Kidd (2005) "The effect of spatial separation on informational masking of speech in normal-hearing and hearing-impaired listeners", JASA, 117 (Figure 1)

Psychometric functions obtained for all listeners
(four NH listeners shown here)

Spatial release from masking (SRM) defined as the difference in Target/Masker ratio between the fitted logistic functions calculated at the 50% correct point.

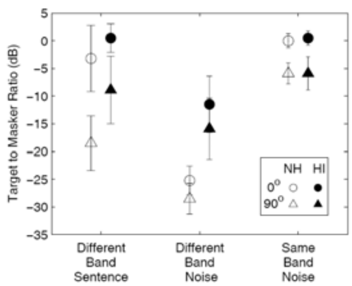
○ 0°
□ 90 °

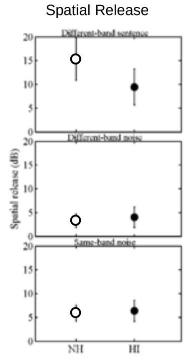
\+ Signal alone



Arbogast et al. (2002) Figure 2

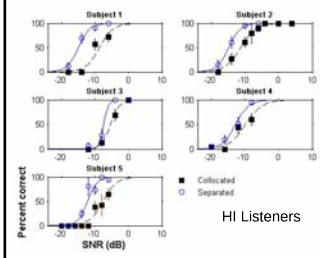
- NH did better and had greater release for the different-band sentence masker
- NH did better on different-band noise, but release was the same
- NH and HI performed identically on same-band noise





Arbogast et al. (2005)
Adapted from Figures 3 and 4

What about with unprocessed speech?



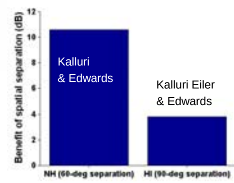
Target: five digit sequences (male talker)

Maskers: continuous speech (two female talkers)

Colocated or, using HRTF simulations, target was directly ahead and maskers were symmetrically placed to the sides.

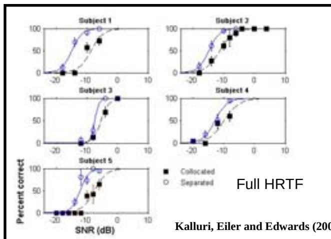
HI listeners were all older.

Again HI listeners derived less benefit from spatial separation.

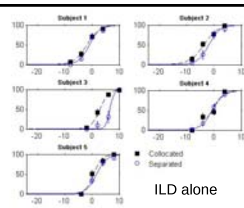


Kalluri, Eiler and Edwards (2007) "The benefit of binaural hearing to spatial perception in normal and hearing-impaired listeners" Hearing Therapies for the Future, NCRAR Biennial Conference, Portland, OR

Kalluri and Edwards (2007) "Impact of hearing impairment and hearing aids on benefits due to binaural hearing" ICA, Madrid, Spain

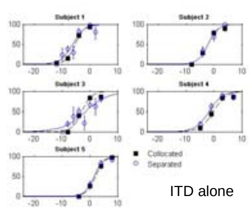


Kalluri, Eiler and Edwards (2007)



Are both time and level differences useful?

Surprisingly, the release obtained with both cues was eliminated when only one was present!



The Implications For Hearing Loss

- Arbogast et al. (2002; 2005) demonstrated that binaural release for primarily informational maskers is greater for NH than HI listeners.
- The results of Kalluri, Eiler and Edwards (2007) suggest that in order to get the full benefit of spatial separation, it is important for HI listeners to have access to both ILD and ITD cues.
- Do modern hearing aids preserve these cues?
- How do reverberant environments affect spatial release?

- 3 female talkers (unprocessed)
- CRM sentences ("Ready Baron…")
- All co-located or symmetrical maskers each at 90°
- HL listened unaided, bilaterally aided, or unilaterally aided (all at equal SL)
- NH listened binaurally or monaurally (earplug and earmuff on one ear)
- Reverberation varied between standard IAC booth ("BARE") or all surfaces covered with Plexiglass panels ("Plex")

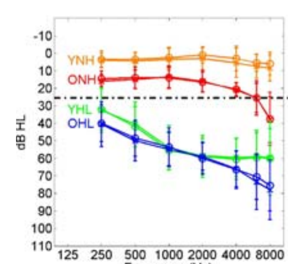
Marrone, Mason, and Kidd (2007) "Listening in a multisource environment with and without hearing aids" Proceedings of ISAAR

Figures by Marrone, except where noted.

10 Younger NH
10 Older NH
10 Younger HL
10 Older HL

Mean ages and range:

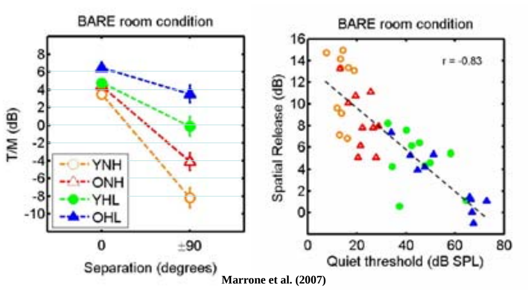
	Normal hearing (NH)	Hearing loss (HL)
Younger	31.4 years 22-43	28.5 19-42
Older	66.2 59-74	69.9 57-80



Marrone et al. (2007)

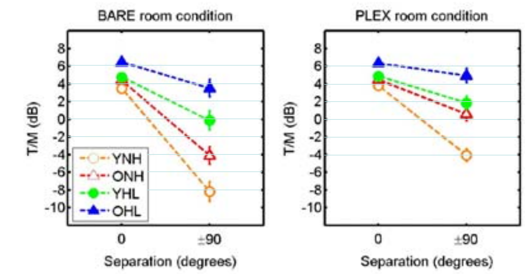
In the less reverberant environment, all four groups received a benefit from spatial separation, despite the fact that there was no “better ear” due to the symmetrical masker placement.

Age and hearing loss resulted in reduced spatial release, with quiet threshold accounting for 65% of the variance across listeners.



Marrone et al. (2007)

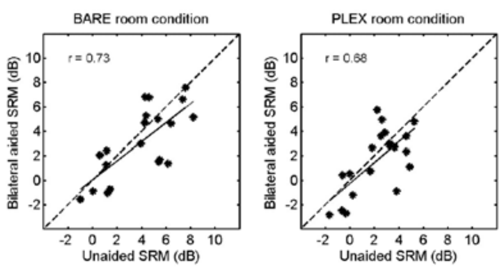
With the addition of Plexiglass to the walls, the reverberation increased and spatial release decreased for all listeners.



Marrone et al. (2007)

Spatial Release from Masking (SRM) with Hearing Aids

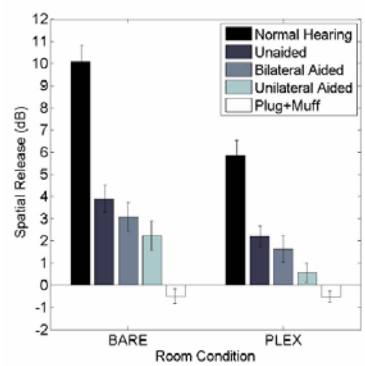
Effect of hearing aids was similar to simply increasing level, since stimuli presented at equal SL in all conditions.



Marrone et al. (2007)

These results clearly show the substantial impact of hearing loss on spatial release from masking.

Hearing aids and aging appear to have less of an effect, at least for these conditions.



Marrone et al. (2007)

How Well Can Hearing Impaired Listeners Use Other Cues to Release from Informational Masking?

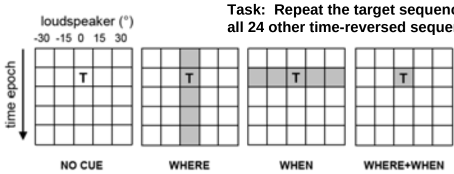
Targets: sequence of five spoken digits

Maskers: time-reversed speech (potential target sequences)

Presentation: five loudspeakers each presenting five “epochs” of sound

Cues: “when”, “where” or “when + where” a target would occur

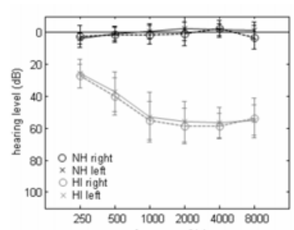
Task: Repeat the target sequence, ignoring all 24 other time-reversed sequences



Best, Marrone, Mason, Kidd and Shinn-Cunningham (2007) “Do hearing-impaired listeners benefit from spatial and temporal cues in a complex auditory scene?”, Proceedings of ISAAR (Figure 2)

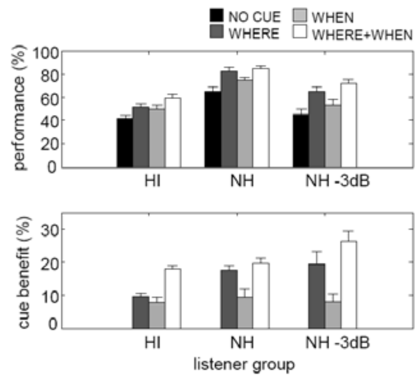
15 Younger Listeners participated

Seven HI, aged 19 – 42
Eight NH, aged 19 – 30



All stimuli presented at 30 dB SL, except in a follow-up condition, (indicated by “NH-3dB” on results slide) where NH repeated experiment with target reduced in level by 3 dB

Best et al. (2007)
Figure 1



HI benefit from cues, but benefit of *spatial* information not as much as for NH listeners.

Best et al. (2007)
Figure 3

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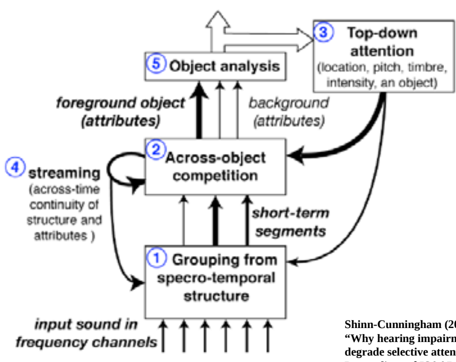


Shinn-Cunningham (2007) "Why hearing impairment may degrade selective attention", Proceedings of ISAAR

Figure 1

The Implications for Hearing Impaired Listeners

- Initial simultaneous grouping cues (e.g., onsets, offsets, modulation, and harmonic structure) and ongoing sequential grouping cues (e.g., location, pitch, and harmonic cues) are degraded by hearing loss and may be distorted by hearing aids.
- Since objects and sound streams are necessary for selectively attending to a target, a less-robust representation of these spectro-temporal cues may lead to reduced competition among objects.
- Reduced competition results in less suppression of sources that would normally be forced into the perceptual background.
- Competing sources that are not suppressed effectively cause greater perceptual interference or "informational masking".

The Implications for Future Work

Future work should focus on:

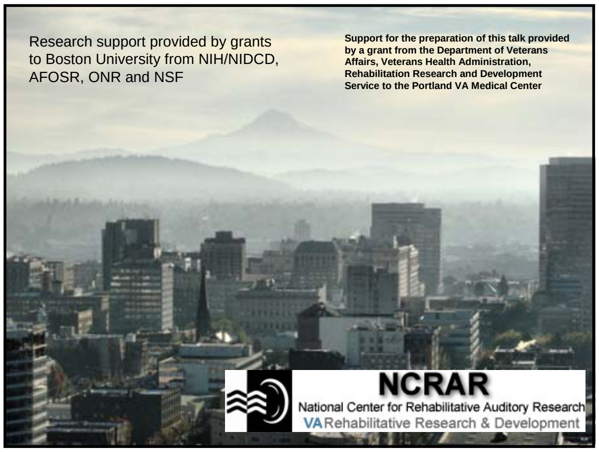
1) **identifying** the cues that lead to the **formation of auditory objects**

2) finding ways to **enhance and preserve** access to those cues through the use of mechanical aids and/or rehabilitative training

Summary

- **Informational masking as it applies to real-world listening by older and hearing impaired individuals is a rapidly expanding area of research.**
- **Currently, the results indicate that the common complaints about hearing loss may be due to a lack of *release* from informational masking rather than greater informational masking overall.**
- **Cues may be further degraded by hearing aid processing, so future work should involve**

  1. **identifying the cues that are most useful**
  2. **ensuring those cues are preserved, and**
  3. **teaching listeners to use them.**



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