Benefits of Spatial Separation for Aided Listening in Older Adults

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Overview
• Speech recognition difficulties of older adults with hearing loss
• Binaural advantages and spatial benefit for speech recognition in noise
• Spatial benefit for aided listening by older adults with hearing loss

Speech Recognition in Noise
• Listeners with hearing loss generally require a more favorable signal-to-noise ratio (SNR) than listeners with normal hearing
• Limited audibility is a major factor
• Hearing aids that restore speech audibility should improve speech recognition

Speech Recognition in Noise
• High-frequency hearing loss makes portions of speech inaudible and reduces audible bandwidth
• Audibility limited by elevated quiet thresholds, not by noise
• To maintain same speech audibility (AI=0.3), speech level increased to improve SNR to -1 dB (5 dB difference)
Speech Recognition in Noise

- Does reduced audible speech entirely account for the more-favorable-than-normal SNRs required by older adults with high-frequency hearing loss?
- Or, do other factors contribute to this deficit, such as peripheral dysfunction, central-auditory changes, or cognitive declines?

After Humes and Dubno (2009)

- To disentangle these factors, noise must limit speech audibility across frequency, rather than elevated quiet thresholds
- Spectral shaping of broadband speech and noise (such as provided by a hearing aid)

After Humes and Dubno (2009)

Overview

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Overview

Binaural Advantages

- Speech recognition improves when speech and noise are separated in space
- Binaural cues
  - Time and intensity differences at the two ears
  - Binaural interaction cues
  - Binaural redundancy
- Head Shadow - acoustical attenuation effect

Binaural Advantages

- Head shadow
  - Head casts an acoustic shadow for higher frequency signals (>1.0 kHz)
  - Higher frequency components of the signal are attenuated at the "far" or "shadowed" ear

Shaw (1974)
**Binaural Advantages**

- For speech recognition in noise
  - Enable speech and noise to be processed separately
  - Combine to overcome the poorer SNR at the ear closer to the noise (near ear)
  - Improve the functional SNR
- Smaller for older adults with normal or impaired hearing?
- If so, does this contribute to their speech recognition difficulties?

**Experimental Conditions**

- Thresholds for HINT sentences
  - Speech always at 0° (from the front)
  - Speech-shaped noise, fixed at 65 dB SPL
  - Speech level adjusted adaptively for 50% correct recognition
- With speech at 0°, spatial separation benefit is difference between:
  - Threshold with noise at 0° (Worse)
  - Threshold with noise at 90° (Better)

**Spatial Benefit**

- For all groups, speech thresholds improved when noise moved from the front (0°) to the side (90°)
- Spatial benefit largest for younger adults and smallest for older adults with hearing loss
- Reduced benefit for older adults with normal hearing

**Effect of Hearing Loss**

- Frequency dependence of interaural level differences (notably head shadow) and high-frequency hearing loss
- Speech information that could be made audible due to an improved SNR in the far ear remains inaudible due to high-frequency hearing loss

**Effect of Amplification**

- High-frequency amplification increases audibility of speech and noise
- Hearing-impaired listener now able to benefit from improved SNR in higher frequencies provided by head shadow (and other binaural cues?)
Overview

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Spatial Benefit for Aided Listening

• Older adults with hearing loss derive less benefit from spatial separation
• Age-related deficit in use of interaural difference cues
• Do bilateral hearing aids improve spatial benefit for older adults with hearing loss?

Spatial Benefit for Aided Listening

• Bilateral hearing aids should:
  • increase speech audibility
  • improve spatial benefit by restoring the availability of interaural timing and level cues
  • allow listeners to take advantage of the improved SNR in the higher frequencies due to head shadow
  • provide binaural redundancy
  • improve directional hearing

Spatial Benefit for Aided Listening

• Aided spatial benefit may be limited:
  • if interaural difference cues are altered
  • Hearing aids work independently at the two ears
  • Hearing aids may be programmed with different compression characteristics or attack/release times
  • if gain is not sufficient to provide increased audible higher frequency speech with spatial separation
  • if listeners cannot benefit from additional binaural cues made available by improved audibility
  • if speech recognition does not improve with increased higher frequency audibility

Spatially Coincident  Spatially Separated

- Speech    Noise
  0°        0°
  Near Ear Head Shadow Better SNR
  Far Ear

- Speech    Noise
  0°        90°
  Near Ear Boost Worse SNR

With Bilateral Hearing Aids

With Bilateral Hearing Aids
Spatial Benefit for Aided Listening

- Unaided vs. aided (hearing aid benefit)
- Babble at 0° vs. 90° (spatial benefit)
- Thresholds for HINT sentences
  - Speech always at 0°
  - Multitalker babble, fixed at 65 dB SPL
  - Speech level adjusted adaptively for 50% correct recognition
- Speech and babble low-pass filtered (1.8, 3.6, 5.6 kHz)
  - Vary presence of binaural cues
  - Vary amount of high-frequency amplification

Aided Audibility Index (AAI)

- Quantifies frequency-dependent changes in simple audibility due to:
  - hearing aid amplification
  - head shadow or boost with babble at 90°
- Does not include binaural listening benefits attributable to binaural processing
- Predict hearing aid benefit
- Predict spatial benefit
- Compare predicted and observed results to separate simple audibility effects from other factors that may contribute to hearing aid or spatial benefits

Research Questions

- Did bilateral hearing aids restore audibility across the full bandwidth of speech?
- Did spatial separation of speech and noise increase audible higher frequency speech?
- Did listeners take full advantage of increased audibility provided by hearing aids and/or spatial separation to improve speech recognition in noise?

Participants

- N=21
- Mean age = 75.3 yr
- Range: 69-83 yr
- Provided bilateral hearing aids, worn for 3-6 months before start of data collection

Ahlstrom, Horwitz, Dubno (2009)

Hearing Aids

- Commercially available
- Digital, four-channel, wide-dynamic range compression
- In the ear (ITE)
- Very slow time constants
- Noise management, expansion, directionality off
- NAL-NL1 fitting strategy
- Fitted by clinical audiologist

Unaided vs. Aided Thresholds

- Overall, thresholds improved with hearing aids (thresholds lower aided than unaided)
- Greater improvement with spatial separation (babble at 90°)
- Greater improvement with more high frequency information (two higher cutoffs)
Unaided vs. Aided Thresholds
• Observed thresholds were poorer than predicted (dashed), especially for aided listening
• With spatial separation and higher frequency speech, observed thresholds were better than predicted

Hearing Aid Benefit
• Significant predicted hearing aid benefit
• Observed significant, but poorer than predicted
• Increased with additional higher frequency information, but only with spatial separation

Thresholds with babble at 0° vs. 90°
• Thresholds improved with spatial separation (thresholds lower with babble at 90° than 0°)
• Thresholds improved with spatial separation more aided than unaided

Spatial Benefit
• Increased with additional higher frequency information, but only with hearing aids
• Better than predicted
• Very little spatial benefit was predicted, unaided or aided

Summary
• Did bilateral hearing aids improve speech audibility?
  • On average: Yes (significant predicted hearing aid benefit)
  • For individuals: Yes and no
  • For some, amplification did not fully compensate for increased higher frequency thresholds (NAL-NL1)
    • Less-than-optimal higher frequency speech audibility likely resulted in:
      • higher-than-normal speech thresholds (more favorable SNRs)
      • limited hearing aid benefit
Summary

• Did bilateral hearing aids restore audibility across the full bandwidth of speech? No
  • Listeners with more high-frequency hearing loss were predicted to require more favorable aided SNRs
  • Consistent with amplification not fully compensating for increased thresholds
  • If optimal audibility achieved, aided thresholds (SNR) should remain constant with increasing hearing loss

Summary

• Did listeners take full advantage of the improved audibility provided by amplification?
  • On average: No (hearing aid benefit was poorer than predicted)
  • For individuals: Mostly no
  • Nearly all aided thresholds (0°) were poorer than predicted
  • Individuals with more high-frequency hearing loss required more favorable SNRs than needed to compensate for their increased thresholds
  • Higher-than-normal SNRs resulted from factors beyond inadequate aided speech audibility

Summary

• Did spatial separation increase audible higher frequency speech?
  • On average: No (no predicted spatial benefit unaided or aided)
  • For individuals: Mostly no
  • Spatial benefit should be larger aided than unaided
    • Amplification should increase speech and babble audibility
    • Head shadow should reduce babble level in the far ear
    • But, higher frequency amplification was limited for many

Summary

• Did listeners benefit from additional binaural cues made available by improved audibility?
  • On average: Yes (spatial benefit was better than predicted)
  • For individuals: Mostly yes
  • Older adults were able to use binaural cues to improve speech recognition in noise
  • This improvement increased with bilateral amplification
  • Hearing aids did not disrupt but enhanced perception of binaural cues

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