Benefits of Auditory Training for Aided Listening by Older Adults

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Outline

• Overview of auditory training
• Speech-perception training programs for older adults who use hearing aids
• Preliminary results with two training programs
• Conclusions
• Future directions and needs
Background

- Early training programs designed for children with severe hearing loss
- Newer training programs target older adults who use hearing aids
  - More moderate hearing loss
  - Higher level deficits?
  - Age-related cognitive declines?
- May limit effectiveness of interventions that focus solely on improving audibility
Hearing Aid Benefits and Limitations

- Speech recognition in quiet:
  - Older adults need increased speech audibility
  - Hearing aids improve audibility in quiet
Hearing Aid Benefits and Limitations

- Speech recognition in noise:
  - Older adults need improved signal-to-noise ratios (SNR)
  - Hearing aids do not significantly improve SNR for speech in noisy environments
How to Improve the SNR?

• Use technology
  • FM systems
  • Noise reduction circuits
  • Directional microphones

• When technology fails, train the listener to use available speech information
  • Speech reading
  • Auditory training
  • Cognitive training?
Effectiveness of Auditory Training

- Improvement on the trained task
- Generalize to improvements for:
  - Novel speech materials
  - Novel talkers
  - Novel competing messages
  - Other auditory measures
  - Self-report communication benefits
  - Non-auditory measures beyond communication
- Retention of improvements after training ends
- Compliance and engagement
Effectiveness of Auditory Training

• Systematic review (Sweetow and Palmer, 2005)
  • Individualized training for adults with hearing aids
  • Little evidence for effectiveness outside clinical environment
  • Some evidence to support efficacy

• Meta analysis (Chisolm and Arnold, 2012)
  • Included studies of systematic review + more recent
  • Individual studies have small effects sizes
  • “Equivocal” or “suggestive” benefit
  • Small, but reliable benefit for short-term improvement
Effectiveness of Auditory Training

- Systematic review (Henshaw and Ferguson, 2013)
  - Individual computer-based auditory training
  - 13 studies - with or without hearing aids
  - Improvements on trained task, with generalization
  - Improvements small and not robust
  - “Published evidence...cannot be reliably used to guide intervention at this time”
  - Need for high-quality evidence of efficacy of training
Effectiveness of Auditory Training

- Other advancements
  - Auditory and cognitive skills, communication strategies
  - Physiological evidence to study mechanisms
  - New programs for older adult hearing-aid users
    - CASPER (Boothroyd, 2010)
    - Read My Quips (Levitt et al., 2009)
    - CAST (Fu and Galvin, 2007)
Speech-Perception Training Programs

• Stimuli
  • Individual sounds (consonants, vowels, clusters)
  • Commonly used, meaningful words in isolation
  • Words in phrases or sentences with context

• Realistic listening environments
  • For training and testing
  • Multiple talkers
  • Listening with competing sounds
  • Speech-like, fluctuating backgrounds
Speech-Perception Training Programs

• Assure optimal audibility
  • Spectral shaping of speech and competition
  • Trainees use their own hearing aids

• Newer technology via computer
  • Automated presentation and scoring
  • Closed-set format / touchscreen monitor
  • Adjustable, customized training paradigms
  • Extended durations of training
  • Adaptable to home-based training
Speech-Perception Training Programs

• Displays and feedback
  • Auditory only
  • Auditory + video + visual/orthographic
    • Visual word form remaps degraded phonological representations (auditory word form) through cross-modal feedback

• More emphasis on roles of
  • Comprehension
  • Contextual information
  • Cognitive function
Speech-Perception Training Program

• Indiana University (IU) Word-Based Training
Speech-Perception Training Program

- Indiana University (IU) Word-Based Training
  - Key findings:
    - 20%+ increase for trained words and phrases
    - Generalized to sentences / novel talkers
    - Greater benefit with auditory + visual feedback
    - Some benefit retained after 6 months

After Burk et al. (2006)
New Study - IU Training

• New investigators and laboratory outside IU to replicate training outcomes for communication
• Well-matched control group of older adults
• Expanded cognitive battery
• Additional training outcomes
  • Physiology (pupillometry)
  • Neurobiology (functional neuroimaging)
MUSC Participants

- Training group (trained 2-4 times weekly)
  - N = 14 (6 females)
  - Mean age = 71.1 Range = 61-85

- Control group (contacted by phone weekly)
  - N = 15 (6 females)
  - Mean age = 69.6 Range = 60-88

- Matched for age, gender, high-frequency hearing loss, test ear, handedness, cognitive function
- No experience with hearing aids
Audiograms and Spectral Shaping

- Spectral shaping to achieve ≥20 dB SL through 3-4 kHz
- To replicate a well-fit hearing aid
- Listen monaural (earphone)
# Cognitive Battery

<table>
<thead>
<tr>
<th>Cognitive Domain</th>
<th>Neuropsychological Tests</th>
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<tbody>
<tr>
<td>General Intelligence</td>
<td>WASI</td>
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<tr>
<td>Attention/Executive Function</td>
<td>Connections Test, Continuous Performance Test, Visual Search &amp; Attention Task, WJ-III Numbers Reversed, WMS III Abbreviated</td>
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<tr>
<td>General Language</td>
<td>WJ-III Picture Vocabulary</td>
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<tr>
<td>Phonological Processing</td>
<td>WJ-III Sound Blending, WJ-III Incomplete Words</td>
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</table>
Procedures - Training Group

- **Train** (Closed Set)
  - 600 frequently occurring words (4 talkers)
  - 94 frequent 4-5 word phrases (4 talkers)

- Speech-shaped fluctuating noise (2-talker ICRA)

- SNR set based on pre-training open set word recognition, to avoid floor and ceiling

- Self-assessment of task load (listening effort) after each training session
Auditory and visual/orthographic display and feedback
Press the red and green buttons to hear the words. Press OK to continue.

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Presented

Incorrect selection
Procedures - Training and Control

- **Pre-Test (Open Set)**
  - 200 easy training words (50 words x 4 talkers)
  - 94 training phrases (4 talkers)
  - 200 VAST Sentences (50 sentences x 4 talkers)
  - 20 CID Everyday Sentences (1 talker) [CID1]

- **Post-Test (Open Set)**
  - Trained words and phrases
  - Untrained VAST and CID sentences
    - + 20 novel CID Sentences [CID2]
  - Same ICRA noise and SNR
Individual Results - During Training

- First to last: Changes during training
- Word recognition improved by 18.2 rau (11.4 - 40.8 rau)

Total training ~33 hours
Individual Results - During Training

• Significant improvements continued through 96 blocks (12 sessions)

Total training ~33 hours
Individual Results - During Training

- Rates of improvement
  - Scores for each training day
  - Fit by growth curve analysis
  - Darker colors are older
  - Circles are changes in rate
  - Trainees with better scores finished more quickly
  - Longer training times → more constant rate of improvement
  - Largest benefit about halfway (blue circles)
  - Most continued to benefit until final sessions (red circles)
Group - Pre-test vs. Post-test

- Significant **trainee** improvement in open-set recognition of trained words and phrases in noise
- Significant generalization to untrained sentences/talkers
- Replicates IU results
- No association with cognitive function
- No significant improvement for **control** group
Individual - Pre-test vs. Post-test

- All trainees improved significantly for trained words

![Graphs showing change in score for training and control groups. The training group shows a significant increase in scores, while the control group shows little to no change.](image)
Individual - Pre-test vs. Post-test

- Most trainees improved significantly for trained phrases
Individual - Pre-test vs. Post-test

- Most trainees improved significantly for untrained sentences (same noise, same talkers as training)
Individual - Pre-test vs. Post-test

- Fewest trainees improved significantly for untrained sentences (same noise, but novel talker)
Additional Training Outcomes

• Quantify benefits beyond communication
  • Attentional demands
  • Listening effort
  • Effects of task difficulty

• Pupillometry

• Neural systems supporting speech recognition?
  • Changes following training-related improvements

• Functional neuroimaging (fMRI)
Pupillometry - Measure of Task Difficulty

- Listening in challenging environments exerts mental and physical demands
  - With limited or degraded speech information
  - For older adults
- How easily or effortfully is a listening task accomplished?
- Effects of training?
- Objectively monitor changes in cognitive effort through measures of pupil diameter

Piquando et al. (2010); Zekveld et al. (2010, 2011); Kuchinsky et al. (2013, 2014)
Results - Pupillometry

- Before training (N=21)
- Same shaping, ear, words, noise
- Easier vs. harder SNR
- Pupil response significantly affected by listening difficulty, even for correct trials

Kuchinsky et al. (2013)
Results - Pupillometry

- Training group: Pre vs. Post
- Control group: First vs. Last

- Significant post-training changes in pupil response even for correct trials
- No significant change for control group
Neural systems underlying successful training

• fMRI task
  • Inside scanner
  • Listen to training words (sparse sampling)
  • Press a button to indicate if word is recognized
Preliminary Results - Neuroimaging

- Following training, increased activity in attention regions important for
  - Orienting to sensory input
  - Evaluating performance
    - MFG = middle frontal gyrus
    - SPL = superior parietal lobule
Preliminary Results

- Does not always relate to communication

- Pupil response shift suggests training reduced attentional demand
- Does not appear to relate to training improvement

- Increased engagement of neural attention systems for sensory input
- May relate to training improvement
Speech Perception Assessment & Training System (SPATS)

- JD Miller, CS Watson, and colleagues
- Multi-site study
  - 2 initial sites (MUSC, Portland VA/OHSU - MR Leek)
  - 4 new sites (Hospital, University Clinics)
- 150 adults training with their own hearing aids
- 75 adults in active control group (story listening)
SPATS - Multi-site Study

- Benefit of extended training (~30 hours) to hearing-aid use and satisfaction
- Benefit of syllable training to sentences
- Predict training benefit from
  - Pre-training speech recognition
  - Spectral and temporal resolution
  - General cognitive abilities
  - Linguistic skills
- Retention
- Engagement
SPATS Participants

- **Training group**
  - N = 24 (4 females)
  - Mean age = 71.3
  - Age range = 54-86
- **Control group**
  - N = 12 (4 females)
  - Mean age = 72.3
  - Age range = 59-82
- Trained and tested with own hearing aids
- Preliminary data - study ongoing
Additional Assessments

- Dementia, reading level, vision screenings
- Spectral and temporal resolution (non-speech)
- Cognitive function
  - Matrix reasoning
  - Vocabulary
  - Working memory
  - Perception of visually fragmented sentences
- Hearing-aid satisfaction
- Self-assessment of task load/listening effort (MUSC)
- Pupillometry (MUSC)
- Exit interview
SPATS

- **Train** (Closed set)
  - Word onsets, Medial vowels, Word endings
  - 4-7 word sentences (corpus of 1,000)
  - 8-12 talkers
  - Quiet and multi-talker babble
  - 15 hrs syllables + 15 hours sentences (3 orders)
• **Train:** Closed set sentences in babble
  • SNR varies from -10 to +10 dB
  • Encourages use of auditory cues and context
  • Score based on errors and “temporal penalties”
• **Train:** Closed set sentences in babble
  - SNR varies from -10 to +10 dB
  - Encourages use of auditory cues and context
  - Score based on errors and “temporal penalties”

---

**Diagram: SPATS Sentence Recognition Practice**

- No response within 5 sec
- Incorrect selections: Sentence replayed
- Correct selection

**Example Sentence:**

“It has been a great year”
SPATS - Testing

- Pre-Test and Post-Test
  - Trained Word onsets, Medial vowels, Word endings
    - Similar sounds, different response format

**SPATS QUICK TEST**
Perception of Syllable Constituents

Onset: “new”

Click on what you heard.

**SPATS QUICK TEST**
Perception of Syllable Constituents

Ending: “birds”

Click on what you heard.
SPATS - Testing

- Pre-Test and Post-Test
  - Untrained words and sentences in babble
    - Words in Noise Test (WIN) - SNR
    - Quick Speech in Noise Test (QuickSIN) - SNR
    - Connected Speech Test - Audio only (CST-A)
    - Connected Speech Test - Audiovisual (CST-AV)
  - Different response formats
  - Different competing messages
  - Different listening strategies
SPATS Results - During Training

- First to last: Changes during training
- Syllable recognition improved by ~6 rau
- Sentence recognition improved by 10 rau

Total training ~30 hours
SPATS Results - During Training

- Self-report ratings of task load obtained after each training session
- Ratings decline for effort and frustration
- Ratings asymptote for mental demand
SPATS Results - Training

- Most trainees improved significantly for trained sentences
SPATS Results - Training

- Most trainees improved significantly for trained syllables
SPATS Results - Training

- Fewer trainees improved significantly for syllables in babble
Group - Pre-test vs. Post-test

- Significant improvement in syllable recognition
Individual - Pre-test vs. Post-test

- Improvement for trainees for syllables (rank order)
Individual - Pre-test vs. Post-test

- Some trainees improved significantly on word onsets
Individual - Pre-test vs. Post-test

- Some trainees improved significantly for medial vowels
Individual - Pre-test vs. Post-test

- Most **trainees** improved significantly for word endings
Group - Pre-test vs. Post-test

- No significant improvement for untrained sentences
- Novel sentences, talkers, babble, listening strategy

![Graph showing comparison between training and control groups for CST with and without audio and visual cues.](image-url)
Group - Pre-test vs. Post-test

- Effects of pre-test score?
- For trainees, higher pre-test scores predict less change
Group - Pre-test vs. Post-test

- Small trainee improvement in SNR for untrained words and sentences ($p=0.08$)
- Novel sentences, talkers, babble, listening strategy
Predicting Training Benefit

- Degree of hearing loss
- Spectral and temporal resolution (non-speech)
- Cognitive function
- Self-report mental and physical demand
- Pupillometry (ongoing)

- Hearing aid characteristics
  - Amount of gain
  - Match to target
  - Weighted aided response
Predicting Training Benefit

- For trained syllable onsets
- Larger aided response predicts more improvement with training
- Aided response
  - Not related to degree of hearing loss
  - Strongly related to how well response matches targets
- More training benefit with a “well-fit” hearing aid
Predicting Training Benefit

- Aided response does **not** predict training benefit for
  - Medial vowels
  - Syllable endings
  - Sentences
  - Untrained words and sentences in babble
Conclusions

• Significant improvements in open-set recognition of trained sounds, words, phrases, sentences
• Some generalization to untrained stimuli
• Generalization may vary with differences in
  • Task
  • Competing noise
  • Listening strategy
Conclusions

- Large individual differences in training benefit
- Good pre-training performance may limit benefit
- Listening effort may decline with training
- No association of training benefit with cognitive function
- Additional predictors of training benefit to be determined
Future Needs

• High-level evidence needed to support effectiveness of auditory training for older adults as a supplement to aided listening in noise
  • Predict who will benefit
  • Assess compliance and engagement, especially for home-based training
  • Discover benefits beyond communication
• Increase access with new tools
  • Home-based systems
  • Tablet platforms
  • Mobile apps for download
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