How auditory and cognitive processing interact when older adults listen

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Outline

1. Who are older adults?
2. Why connect audition and cognition?
3. Auditory aging
4. Cognitive aging
5. Assessment issues (impairment)
6. Rehabilitation issues (activity)
7. Accessibility issues (participation)

Longevity

- Chances of living to 65
  - a century ago: < 1 in 20
  - 1980: 1 in 10
  - 2000: 1 in 5

- Centenarians/100,000
  - 2006
    - USA: 18
    - Japan: 23
    - Canada: 15

- Future increase in USA
  - 2004: 67,473
  - 2040: 580,605
The aging population 1966-2006

USA 2006

Next 40 years…

> 65 years: 2004 – 12% 2050 – 21%
Outline

1. Who are older adults?
2. Why connect audition and cognition?

Function of person in environment

- Little problem in ideal listening conditions
  - Quiet
  - One talker
  - Familiar person, topic, situation
  - Simple task, focused activity

- Difficulty in challenging listening conditions
  - Noise
  - Multiple talkers
  - Strangers, accents, new topic, novel situation
  - Complex task, many concurrent activities
  - Fast pace

Auditory & cognitive hypotheses

- Site-of-lesion View
  (e.g., CHABA, 1988; Humes, 1996)
  - Peripheral Auditory vs
  - Central Auditory vs
  - Cognitive

- Perceptual-Cognitive Interactions
  (e.g., Lindenberger & Baltes, 1994; Baltes & Lindenberger, 1997)
  - Information-degradation
  - Deprivation
  - Cognitive Load
  - Common Cause
World Health Organization
International Classification of Functioning (2001)

- Health Condition
  - Disorder or disease
- Body Function & Structure
- Activity
- Participation

Environmental Factors
Personal Factors

Cognition & everyday function

- IJA 2003: International Consensus (Eriksholm 2001)
  - WHO ICF Concepts (www.who.int/icidh; Schow & Nerbonne, 2006)
    - Auditory: hearing
      - analysis of acoustical signal (impairment)
    - Auditory & Cognitive
      - Listening: intention and attention (activity)
      - Comprehending: interpretation of meaning (activity)
      - Communicating: social interaction (participation)
- The soundbooth vs the real world
  - Professional vs patient views on HL
- “Ease/effort of listening”
  - Professional vs patient views on HL

Bottom-up & top-down processing

- Listening comprehension
  - Bottom-up processing
    - Analysis of signal
  - Top-down processing
    - Alternatives constrained by lexicon, world knowledge
- As listening becomes effortful
  - Bottom-up processing less efficient
  - Top-down processing more necessary
Cognition & HA benefit correlated

- Landmark 2003 studies
  - (Gatehouse et al.; Humes; Lunner)
    - Those with higher cognitive function
    - Those with lower cognitive function
    - Do better to complex, fast-acting signal processing
    - Do less well to such complex devices
- Cognition matters in challenging conditions

Why?

- How measure cognitive status?
  - To predict or guide treatment (HA fitting, training)
  - As a new outcome measure

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1. Who are older adults?
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3. Auditory aging

Auditory aging

Mills, Schmeidt, Schulte, & Dubno, 2006

- HF audiometric threshold elevation
  - OHC (also noise-induced hearing loss)
  - Endocochlear potentials ~ stria vascularis
- Neural – loss of synchrony
Speech as a signal: Temporal cues

- Syllabic patterns
  - prosody (speech rate, rhythm)
- Onsets/offsets or gaps/durations
  - phonemic contrasts (apple – ah)
- Synchrony/periodicity cues
  - fundamental frequency & harmonic structure (voice pitch, quality)

Levels of temporal processing
(Pichora-Fuller & MacDonald, 2007, ISAAR)

<table>
<thead>
<tr>
<th>Cue Type</th>
<th>Role in Speech</th>
<th>Experimental Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periodicity</td>
<td>Psychoacoustic</td>
<td>Speech</td>
</tr>
<tr>
<td>(synchrony phase)</td>
<td>Frequency DL</td>
<td>F0 DL</td>
</tr>
<tr>
<td></td>
<td>MLD</td>
<td>Speech MLD</td>
</tr>
<tr>
<td></td>
<td>High-level intensity DL</td>
<td>Identification of concurrent vowels, jittered speech</td>
</tr>
<tr>
<td>Gaps/durations</td>
<td>Voice</td>
<td>Phoneme contrasts</td>
</tr>
<tr>
<td>(onsets/offsets)</td>
<td>(quality, identity, clarity, segregation)</td>
<td>Gap detection</td>
</tr>
<tr>
<td>Envelope</td>
<td></td>
<td>Phonemic contrasts</td>
</tr>
<tr>
<td>(modulation)</td>
<td></td>
<td>(stops, VOT)</td>
</tr>
<tr>
<td></td>
<td>Prosody</td>
<td>Duration discrimination</td>
</tr>
<tr>
<td></td>
<td>(rate, rhythm, stress)</td>
<td>Intelligibility of noise-vocoded, compressed speech</td>
</tr>
</tbody>
</table>

Periodicity & age-related differences

- Physiology
  - Neural degeneration
- Psychoacoustics
  - Binaural MLDs
  - Frequency DLs at low-frequencies
  - High-level intensity DLs
- Speech
  - F0 DLs
  - Concurrent vowel identification (streaming)
- Music
  - Tonality in music
Simulating temporal aspects of auditory aging
(Pichora-Fuller & Souza IA, 2003; Pichora-Fuller, Schneider, MacDonald, Brown & Pass, 2007)

- Compare performance of young and old listeners on speech and cognitive tasks
- Control auditory factors
  - Match young and old
  - Equate stimulus conditions
  - Simulate hearing loss
  - Control range of HL and age

Periodicity – Voice cues

![Figure 8.1](image)

Figure 8.1: The waveform during a short period (a little over two vocal and /æ/ sounds in the pronunciation of CAT, as in “caught”)

Loss of neural synchrony

- Aging results in more error in phase locking
  - (poorer synchrony or “jitter”)
- Consider as a mild form of auditory “neuropathy”
Jittering a tone or speech
(Pichora-Fuller et al., 2007, Hearing Research)

Jittered example

- Intact
- Jittered

Spectrograms for jittered and intact sentence in babble
Word identification results

Old = young jittered in LOW-CONTEXT
- Equates for quality of input for bottom-up processing

Are older adults special?

- Audibility (audiogram) is primary but not a special aging factor (Humes, 2003, JAAA 2007)
- If audibility factor is minimized
  - Age-related auditory temporal processing issues emerge
    - Especially in challenging listening conditions
      - Complex speech (e.g., sentences)
      - Complex backgrounds (e.g., competing talkers)
    - Critical age differences when conditions become challenging
      - Older listeners need better S:N than younger listeners
- Cognitive factors important in challenging conditions!!!
  - Regardless of age
  - Regardless of audiogram

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Factors influencing comprehension

EXTERNAL Contextual Factors
- Social Supports
- Physical Supports

PERCEPTION Sensory Factors
- Hearing
- Vision
- Touch
- Smell
- Taste

INTERNAL Cognitive Factors
- Knowledge
  - World Knowledge
  - Linguistic Knowledge
- Processing
  - Memory
  - Attention

Knowledge is preserved in aging
- Knowledge is preserved in long-term memory
  - Semantic memory (world knowledge)
  - Episodic memory (personal history)
  - Procedural memory (how to do things)
- Linguistic knowledge
  - Vocabulary
  - Syntax
  - Phonology

Processing information changes
- Processing is slowed
  - Perception
  - Cognition
- Performance varies with time/timing of task components
Working memory

- System responsible for the processing and temporary storage of information
  - during the performance of all complex cognitive tasks, including comprehension
  - assumed to have a limited capacity that must be shared between processing and storage
  (Baddeley, 1976)

Working memory differences

- Individuals differ in working memory capacity
  - Those with inefficient processes have functionally less storage capacity
    - they must allocate more of the available resources to processing
  - WM span is highly correlated with language comprehension
    - WM span for reading and listening are highly correlated
      (Daneman & Carpenter, 1980)
  - Working memory declines with age
    (Wingfield & Stine-Morrow, 2000)

Possible cognitive factors in aging

- Knowledge is preserved and context is helpful
  - BUT Processing is less efficient
    - Slowing
    - Working memory
    - Attention
  - All are reasonable cognitive consequences if sensory (or motor) abilities are reduced
Coordinate bottom-up & top-down processing

Cognitive neuroscience of aging
- Same performance with different processing
- More widespread activation ~ brain reorganization
  - Young brain activity more lateralized
  - Old brain activity more distributed
  - Low-performing older adults have even more distributed activation
- Deterioration or compensation?
- HAROLD: Hemispheric asymmetry reduction in older adults (Cabeza, 2002)

Supporting perception
(Pichora-Fuller, Schneider & Daneman, JASA, 1995)
- SPIN: 8 lists of 50 sentences
  - Half low-context
    - John did not talk about the feast.
  - Half high-context
    - The wedding banquet was a feast.
- Repeat last word of sentence
- WM task added
- Vary S/N
  - Conversation at 65 dB SPL
  - Noise in home at 50 dB SPL
  - +15 dB S/N in quiet living room
  - -2 dB S/N in subway/aircraft
Context, intelligibility & brain activation
(Obleser, Wise, Dresner & Scott, 2006)

High vs. low predictability at intermediate signal quality for noise-vocoded SPIN sentences

Activation to HIGH-CONTEXT 8-band > LOW-CONTEXT 8-band speech

Various areas activated including the left dorsolateral prefrontal cortex (working memory and semantic processing)

Equating for perceptual difficulty

Effortful listening zone
- Low-context and high-context curves separated
- Everyone remembers less in this zone than in easy S:N conditions

Noise and discourse comprehension
(Schneider, Daneman, Murphy, Kwong See, 2000)
Spectrograms:
Jitter simulation of temporal aspects of auditory aging vs intact sentence in babble

Effect of simulated auditory aging on working memory span

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**Intelligibility and cognitive ability**
(Lunner & Sundewall-Thorén, JAAA 2007)

Explained SNR variance from hearing loss and cognitive performance

- Slow & Unmod.
- Fast & Mod.
- Fast & Unmod.
- Slow & Mod.

**Hearing Aid Compression & Cognition**
(Lunner & Sundewall-Thorén, JAAA 2007)

Explained SDR variance from hearing loss and cognitive performance

**Inter- & intra-individual differences**
(Pichora-Fuller, Phonak Adult Conference, 2007)

- **INTER**: Individuals differ in WM capacities
  - Fred
  - Mary

- **INTRA**: Allocation of capacity resources to processing vs storage varies with task demands

<table>
<thead>
<tr>
<th>Bottom-up processing</th>
<th>Top-down processing</th>
<th>WMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fred in quiet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fred in noise</td>
<td></td>
<td>WMS = 6</td>
</tr>
<tr>
<td>Fred in more noise</td>
<td></td>
<td>WMS = 2</td>
</tr>
</tbody>
</table>
Hearing loss associated with dementia

- Weinstein & Amsel (1986)
  - N=30 institutionalized elders with senile dementia
  - 10 of 30 reclassified to less severe category of dementia when retested with amplification
  - (83% had hearing loss > 25 dB HL, significantly higher than comparison sample w/o dementia)

- Uhlmann et al. (1989)
  - Case-control study with 100 pairs
  - Prevalence of hearing loss significantly higher in those with Alzheimer’s-type dementia
  - Hearing loss significantly correlated with MMSE

- Gold, Lightfoot & Hnath-Chisolm (1996)
  - 27 of 30 (90%) patients with Alzheimer’s had hearing impairment (used pure-tone screen & HHI)

“Central Auditory” Problems May PRECEDE Dementia

- Two studies from Framingham Cohort
  - Gates et al. (1996)
    - N>700, speech in competing speech test (SSI-ICM) given to those without stroke, dementia, or hearing loss (PTA)>40 dB HL
    - MMSE administered 2, 4, 6 yrs later
    - Those with low scores on SSI-ICM were 6-12 times more likely to develop clinical dementia
  - Gates et al. (2002; also recent E&H)
    - Similar results for longer follow-up period (3-12y)

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Contextual Support & Compensation
(Pichora-Fuller, IJA Supplement, 2008)

- Semantic-Syntactic
- Lexical
- Phonological

Speech Intelligibility in Noise

Kryter 1994 – based on ANSI 1969

Sentence Level: Semantic-syntactic
Word Identification Results

- Old = young jittered in LOW-CONTEXT
  - Equates for quality of input for bottom-up processing
- Old better than young jitter in HIGH-CONTEXT
  - More expert at top-down processing

![Graph showing Word Identification Results](image1)

Benefit from Context

- Old benefit from context more than young.

![Graph showing Benefit from Context](image2)

Phonological Immunization?
(Pichora-Fuller, Schneider, Benson, Hamstra, & Storzer, JASA, 2006)

- Gap Detection Threshold (msec)

![Graph showing Phonological Immunization](image3)
Summary
- Noise makes listening effortful
- Older adults have problems with temporal processing at various levels:
  - Envelope, gaps, periodicity
- Older listeners need about 3 dB S/N more
- If listening is effortful then cognition matters
- Context compensates for perceptual problems
- Inter-individual differences (ability to use context varies with cognition)
  - An input factor
- Intra-individual differences (effort varies with environment)
  - An outcome factor

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Care & Contexts
- Independent Living (Family vs Alone)
- Home Care
- Peer and self help groups
- Adult Day Care
- Residential Care
  - Graduated care
  - Levels of care (independence >> dependence)
- Hospital to hotel-like?
Inter-dependence

- Close relationships
  - Individuals strongly defined by relationships
  - Individual identities may become inseparable

Negative Aspects: Ageist Stereotypes?

Self-presentation and stereotypes

- Self-censorship to minimize problems
  - Whether youth or elder
- Present as being competent member of advantaged group
  - Teens want to appear older
  - Elders want to appear younger
- Gain/maintain control of self/other
Attribution

- In-group
  - Negative behavior ~ situation
  - Positive behavior ~ person
- Out-group
  - Negative behavior ~ person
  - Positive behavior ~ situation

"Anti-aging" vs "pro-age"

When? Predicament/Enhancement Models

- Ageist Stereotypes fuel communicative incompetence.
- Dependent behaviours are reinforced and independent behaviours are ignored by nurses in residents of care facilities (Margaret Baltes).

Interesting facts about US seniors

- > 50 yrs own 70% total network of households
- 90% of older adults have living children
  - 80% have ‘close’ relationships
  - 15% live with adult children in US
- 19% had higher education
- 9.1 million veterans
- 5 million in labor force
- TV viewing increases with age
  - More leisure time (also music)
- Fastest growing age group in internet use
- > 65 years: > 8 physician visits/year in US
Hearing and use of general communication & information technologies
(Gonsalves & Pichora-Fuller, Cdn J Aging, 2008)

Questions for future R & D
- Brain plasticity, activation, working memory
  - Plasticity as a mediator of cognitive status & HA adjustment?
    - Measure WMS
    - Inter-individual diffs (perception controlled)
    - Intra-individual diffs (very perceptual demands)
    - Embed in existing audiology tools
- Role of types of contextual support vs listening challenges
  - Variations (in top-down processing) due to listening tasks/environments
  - Context is an excellent basis for therapy
- On-line listening vs off-line speech tests
  - Insights into processing (imaging, ERP, eye-tracking)
- Purposes
  - HA design/fitting & training program development
  - Prediction/assessment/planning
  - Outcome evaluation
- Respecting expertise and preserving competence
  - Right kinds of social support at right time

Colleagues & students
- Bruce Schneider
- Meredith Daneman
- Bruce Ben-David & Craig Chambers (eye tracking studies)
- Ingrid Johnsrude (MRI studies)
- Natalie Phillips (ERP studies)
- Frank Russo (music and aging studies)
- Shern Smith & Richard Wilson (speech perception, hearing loss and aging studies)
- Pascal van Lieshout (speech production in noise studies)
- Tracy Anselmo
- Quan Hu
- Marco Coletta
- Kate Gugino
- Payam Erezhanian
- Reiner stump
- Huiwen Goy
- Marie MacDonald
- Hollis Pass
- Maxime Pelletier
- Bob Quilich
- Bruce Sheldon
- Gurjit Singh
- Tara Yongpaisal
Further Reading

- Special issues of on aging and/or cognition and hearing
  - Trends in Amplification 2006
  - Seminars in Hearing 2006
  - Phonak book on “Hearing Care for Adults” May 2007
  - Sequel conference to be held in Chicago November 2009
  - 2008 special issue of UJA on “Signal to Dialogue”
Further Reading:

Many of my writings listed below are reviews that appear in special issues of journals or in books concerned with aging and communication. These works will provide you with many references to the works of other authors and these volumes contain many interesting articles by other authors.

Work in Special Issues of Journals about Aging


(Chosen as one of the best special issues in Audiology in 2003; Hearing Journal, Fall, 2003)

(Chosen as one of the best papers in Audiology in 2003; Hearing Journal, Fall, 2003)


Book Chapters


Newsletters and Magazines


