It’s not just what you hear, but what you can do with what you hear – linking auditory and cognitive processing

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Speech Understanding in Noise

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

- Difficulty in challenging listening conditions
  - Noise – but it is more than just masking…….
  - Multiple talkers
  - Strangers, accents, new topic, novel situation
  - Complex task, many concurrent activities
  - Fast pace
  - Stress/emotion
  - Hearing aid/cochlear implant
# Auditory-Cognitive Interactions

<table>
<thead>
<tr>
<th>IDEAL</th>
<th>CHALLENGING</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Listener</strong></td>
<td><strong>Listener</strong></td>
</tr>
<tr>
<td>- Younger</td>
<td>vs. older adults</td>
</tr>
<tr>
<td>- Normal</td>
<td>vs. impaired hearing</td>
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<tr>
<td><strong>Signal</strong></td>
<td><strong>Signal</strong></td>
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<tr>
<td>- Intact</td>
<td>vs. distortions/maskers/HA/CI</td>
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<tr>
<td><strong>Task</strong></td>
<td><strong>Task</strong></td>
</tr>
<tr>
<td>- Repeat</td>
<td>vs. comprehend/compute/judge/recall</td>
</tr>
<tr>
<td><strong>Context</strong></td>
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</tr>
<tr>
<td>- Neutral</td>
<td>vs. semantic/spatial/emotional</td>
</tr>
<tr>
<td>- Acoustic</td>
<td>vs. linguistic/physical/social</td>
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</tbody>
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Auditory Aging

- HF audiometric threshold elevation
  - OHC (also noise-induced hearing loss)
  - Endocochlear potentials ~ stria vascularis (Mills et al., 2006)
- Neural – loss of synchrony >>> temporal processing
Temporal Processing and Speech

- Syllabic patterns
  - prosody (speech rate, rhythm)
- Onsets/offsets or gaps/durations
  - phonemic contrasts (apple – al)
- Synchrony/periodicity cues
  - fundamental frequency & harmonic structure (voice pitch, quality)
Speech Perception in Noise
(Pichora-Fuller, Schneider, Daneman, JASA, 1995)

- 8 lists of 50 sentences
  - Half low-context
    - John did not talk about the *spoon*.
  - Half high-context
    - Stir your coffee with a *spoon*.
- Repeat last word of sentence
- Vary S:N
- (Sometimes also recall)
- Old need 3 dB better S:N
- Context helps
Older “normal” hearing for age with clinically normal audiograms up to 4 kHz (N = 48; average age ~ 70 years)
SSQ and Behavioural Hearing Tests: Not Significantly Correlated

Pure-tone Average (dB HL)

Words-in-Noise (WIN) 50% threshold (dB SNR)
SSQ Items with Largest Age-related Differences

- **Speech**
  - Conversing in adverse environment
    - Conversation in echoic environment: 1.7
    - Talking with a person in continuous noise: 1.6
  - Focusing, switching attention
    - Ignore interfering voice of different pitch: 1.9
    - Following conversation switching in a group: 1.6

Young - Old score (10-point scale)
Bottom-Up & Top Down Processing

- Effortful listening
  - Bottom-up processing less efficient
  - Top-down processing more necessary

- Bottom-up (ear to brain)
  - Analysis of acoustic signal
    - Better signal (faster)
    - Poorer signal (slower)
    - @ amount & type of distortion

- Top-down (brain to ear)
  - Priming (pre-signal)
    - expectations facilitate recognition (faster)
  - Disambiguation (post-signal)
    - knowledge constrains alternatives (slower)
  - Repair (post-signal)
    - Fill in gaps or correct errors (slower)
What Changes in Cognitive Development over the Lifespan?
(Craik & Bialystock, Handbook of Cognitive Aging, 2008)

Younger \[\rightarrow\] Older

Control
(PROCESSING)

Representation
(KNOWLEDGE)

Context
(reliance, benefit from SUPPORTIVE ENVIRONMENT)

losses \[\rightarrow\] gains
Auditory-Cognitive Interactions during Processing in Challenging Conditions (with HAs and CIs)

WORKING MEMORY

ATTENTIONAL CONTROL

SPEED OF INFORMATION PROCESSING

HA Benefit Correlated with Cognition

- Landmark 2003 studies (Gatehouse et al.; Humes; Lunner)
  - Those with higher cognitive function
    - do better with complex, fast-acting signal processing
  - Those with lower cognitive function
    - do less well with 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
Cognitive Benefits of Better Hearing
Arlinger, Lunner, Lyxell, & Pichora-Fuller, SJP, 2009

- Older adults using hearing aids have better emotional and social well-being and greater longevity
  (Appolonio et al., 1996; Cacciatore et al., 1999; Naramura et al., 1999; Seniors Research Group, 1999)

- Reduced rate of decline in scores on a cognitive screening test over a six-month period following intervention with hearing aids
  (Allen et al., 2003)

- Slower cognitive decline in Alzheimer’s cases with better hearing
  (Peters, Potter, & Scholer, 1988; Wahl & Heyl, 2003)

- Hearing aid use reduced problem behaviours judged by caregivers of adults with dementia
  (Palmer et al., 1998)
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)
Measuring Working Memory: Why and How….

Fred

Mary

Fred in Quiet

Fred in Noise

Fred in More Noise

Adapted from Pichora-Fuller, 2006
Cognitive Losses with Age

- Processing is less efficient
  - Working memory
  - Slowing
  - Attention/Inhibition

- Possible cognitive consequences if sensory (or motor) abilities are reduced with associated increases in processing demands
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 **2-3 dB better S:N** than younger listeners

- **Cognitive factors important in challenging conditions!!!**
  - Regardless of age
  - Regardless of audiogram

- **BUT THERE IS NO NOISE REDUCTION IN DAILY LIFE!!!!**
Cognitive Aging

- **Gains:**
  - Knowledge is preserved
  - Context is helpful

- **Losses:**
  - Processing
  - Working memory
  - Slowing
  - Attention/Inhibition
Cognitive Neuroscience of Aging

- Same performance achieved with different processing
- More widespread activation ~ brain reorganization
  - Young brain activity more lateralized
  - Old brain activity more distributed
- Deterioration or compensation?
- **HAROLD**: Hemispheric asymmetry reduction in older adults (Cabeza, 2002)
- **PASA**: Posterior-anterior shift in aging (Davis, Dennis, Daselaar, Fleck & Cabeza, 2008)
Context, Intelligibility & Brain Activation
(Obleser, Wise, Dresner & Scott, 2006)

High vs. low predictability at intermediate signal quality for younger adults listening to distorted (noise-vocoded) SPIN sentences

Activation to **HIGH-CONTEXT > LOW-CONTEXT** speech

Various areas activated including the **left dorsolateral prefrontal cortex** (working memory & semantic processing)
Compensation
(Grady, 2012, *Nature Reviews Neuroscience*, 13, 491-505)
Cognitive Hypotheses & Training

- **Cognitive Compensation Hypothesis**
  (Li, Krampe, & Bondar, 2005; Li & Lindenberger, 2002)
  - declining sensory (and motor) functions are compensated by higher-level cognitive and attentional processes

- **CRUNCH - Compensation-Related Utilization of Neural Circuits Hypothesis**
  (Reuter-Lorenz & Cappell, 2008)
  - additional brain regions are recruited by older adults when capacity limits are reached in a given task or combined tasks.

- **STAC - Scaffolding Theory of Aging and Cognition**
  (Park & Reuter-Lorenz, 2009)
  - there is the potential to enhance such compensation by training.
New Rehab Issues

Ease of Listening

1. **Speed and semantic priming**
2. Spatial expectation
3. Emotional consistency
4. Talker continuity
Lexical decision reaction time in younger and older listeners: The effects of semantic context and the type and amount of acoustical distortion.

- Preceding context distorted or intact
  - Congruent: Stir your coffee with a spoon.
  - Neutral: Its name is feast.
  - Incongruent: Stir your coffee with a risk.

- Measure RT when lexical decision correct
- Facilitation (RT neutral context – RT congruent context)

Increasing Distortion of Context Only Slows Lexical Decision for Intact Items
• Older listeners’ RTs are more facilitated by context.
• Signal distortion reduces facilitation.
Speed (and Ease) of Listening

- Signal quality affects listening:
  - Faster if signal is intact
  - Slower if signal is distorted or degraded or noisy
  - *Could be influenced by hearing aid processing*

- Context affects listening:
  - Faster if context is semantically congruent
  - Slower if context is semantically incongruent
  - *Could be influenced by AR training*
New Rehab Issues

Ease of Listening

1. Speed and semantic priming
2. Spatial expectation
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4. Talker continuity
Spatial Attention

- Callsigns = Charlie, Hopper, Baron, etc.
- Probability of target at the centre location (1.0, 0.8, 0.6, 0.33)
- Simple vs Complex instruction

**Task:** Identify colour and number with target callsign

- **Ready Charlie,** go to blue 1 now
- **Ready Hopper,** go to white 2 now
- **Ready Baron,** go to green 8 now

Ready **Baron**, go to [colour] [number] now.
Task Complexity Hurts Older Adults if Target at Unlikely Location

Singh, Pichora-Fuller, Schneider, JASA 2008; revision submitted, Ear & Hearing
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Emotion and Word Recognition
(Dupuis & Pichora-Fuller, in prep; Dupuis PhD; files on T-space)
**Mixed vs. Blocked; Y > O ~ 11% vs. 6%**
New Rehab Issues

Ease of Listening

1. Speed and semantic priming
2. Spatial expectation
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4. Talker continuity
Circles with solid lines: intact two-talker speech masker condition.
Circles with the dashed line: time-reversed two-talker speech masker.
Triangles with solid lines: 3-band speech masker condition.
Triangles with the dashed line: 16-band speech masker condition.
Diamonds: precedence-effect speech masker condition.
Listening in Noise ~
Driving Uphill in Snow

- Low gear (effort)
- Slow down (speed)
- Keep moving (continuity)
- Stay calm (emotion)

- Expertise (training)
- Snow tires (technology)

- Get where you want to go
- Stay safe