ACCEPTABLE NOISE LEVELS
A USEFUL TOOL?

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CAN YOU HEAR ME?

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THIS SESSION IS AVAILABLE FOR 1.1 CEU.
MUST STAY LOGGED ON FOR THE FULL SESSION.
MUST SUCCESSFULLY COMPLETE A SHORT QUIZ.

WHAT IS ACCEPTABLE NOISE LEVEL (ANL)?

• The highest level of background noise someone is “willing to put up with” while listening to speech

WHY ARE ANLS IMPORTANT?

• ANLs can predict, with 85% accuracy, who will be successful with hearing aids (Nabelek et al., 2006)
**Measuring ANLs**

- Listener adjusts speech to a comfortable level

**Measuring ANLs**

- Background noise is added

**Measuring ANLs**

- Listener adjusts the noise to her max tolerable level

- \[ \text{ANL} = \text{speech level} - \text{noise level} \]

**Measuring ANLs**

- Small ANL (willing to listen at poor SNRs) = Successful HA user (Nabelek et al., 2006)

**Measuring ANLs**

- Large ANL (want to listen at high SNRs) = Unsuccessful HA user (Nabelek et al., 2006)
If we knew why some people were unlikely to be successful with hearing aids, we could:
- Better tailor our counseling strategies and technology recommendations to the individual
- Create technologies that improve the aspects of sound that people are objecting to, and thereby improve listeners’ chances of success with hearing aids

ANLs are not related to:
- An individual’s age (Nabelek et al. 1991)
- Locus of control (Nichols and Gordon-Hickey, 2012)
- Interest level of the material (Plyler et al. 2011)

There is conflicting evidence regarding whether ANLs are related to:
- Speaker gender (Plyler et al. 2011; Gordon-Hickey et al. 2012)
- Hearing sensitivity (Nabelek et al. 1991; Nabelek et al. 1991)
- Type of background noise (Lytle, 1994; Nabelek et al. 1991; Crowley and Nabelek, 1996; Gordon-Hickey and Moore, 2007; Gordon-Hickey, 2012)
- Ability to understand speech in noise (Crowley & Nabelek, 1996; Nabelek et al. 2004; von Hapsburg and Bahng, 2006)
- Hearing-aid use (Nabelek et al. 2004; Ahlstrom et al. 2009; Wu and Stangl, 2013)

<table>
<thead>
<tr>
<th>variable</th>
<th>doesn’t matter</th>
<th>It matters</th>
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<tbody>
<tr>
<td>speaker gender</td>
<td>Plyler et al. 2011</td>
<td>ANLs lower w/female talker (Gordon-Hickey et al. 2012)</td>
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<tr>
<td>listener gender</td>
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<td>hearing sensitivity</td>
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<td>type of BGN</td>
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<td>speech understanding</td>
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<td>hearing-aid use</td>
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What does all of this mean?

Why the conflicting results?

- Many differences in study design
  - Test Materials
    - Stimuli
  - Speech
    - Arizona Travelogue or something else?
    - Intelligible?
    - Native language?

Why the conflicting results?

- Many differences in study design
  - Test Materials
    - Stimuli
  - Noise
    - Multi-talker babble? (# and gender of talkers?)
    - Speech-shaped noise?
    - Music?
    - Intelligible?

Why the conflicting results?

- Many differences in study design
  - Test Materials
    - Stimuli
  - Speech-in-Noise Tests
    - Spin?
    - Hint?
    - Other?

Why the conflicting results?

- Many differences in study design
  - Test Materials
    - Stimuli
  - Speech-in-Noise Tests
    - Instructions
    - Published?
    - Modified?
    - Translated?
**Why the conflicting results?**

- Many differences in study design
  - Test Materials
    - Stimuli
    - Speech-in-Noise Tests
  - Instructions
  - Presentation Method
    - Headphones, insert earphones or SF (speaker array)?
    - Monaural/binaural?

**Why the conflicting results?**

- Many differences in study design
  - Test Materials
    - Stimuli
    - Speech-in-Noise Tests
  - Instructions
  - Presentation Method
    - Who controls the stimulus level?
    - Experimenter? Study participant?

**Why the conflicting results?**

- Many differences in study design
  - Test Materials
    - Stimuli
    - Speech-in-Noise Tests
  - Instructions
  - Presentation method
  - Who controls the stimulus level

**Distribution of ANLs**

- Eddins and Arnold et al., 2013

**Why the conflicting results?**

- Many differences in study design
  - Test Materials
    - Stimuli
    - Speech-in-Noise Tests
  - Instructions
  - Presentation method
  - Who controls the stimulus level?
  - Subject pool
  - Poor Test-Retest?
What does all of this mean?

- Many differences in study design make it difficult to compare results across studies to determine what’s really going on and which variables really matter

Summary

- Instead of trying to determine what variables affect ANL, what if we determined why people are willing to accept the amount of background noise that they are willing to accept?
  - Knowing the answer to this may help us determine:
    - Which variables are most likely to affect a listener’s ANL (and why)
    - What we can do to improve a listener’s ANL (and presumably his chances of success with hearing aids)

Time to change our perspective?
**RESEARCH QUESTIONS**

• How are people deciding how much background noise they are willing to accept?
• What can we do about it?

**POTENTIAL ANL CUES**

• Loudness?
• Listening Effort?
• Annoyance?
• Speech Intelligibility?
• Other?
• Some combination of the above?

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**QUESTIONNAIRE STUDY**  
Recker et al. 2011

• Investigated the perceived negative impact that BGN has on:
  – Speech intelligibility
  – Stress levels
  – Concentration levels
• It asked participants about:
  – How bothersome they find BGN
  – Their own perceived tolerance for BGN
  – Whether they avoid situations known to have high levels of BGN

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**QUESTIONNAIRE**  
Recker et al. 2011

1. In noisy situations (e.g., a crowded restaurant or bar), I ________ more difficult to concentrate than when in quiet situations.

   a. find it much
   b. find it somewhat
   c. find it slightly
   d. rarely find it any

2. In noisy situations (e.g., a crowded restaurant or bar), I ________ more stressed than when in quiet situations.

   a. feel much
   b. feel somewhat
   c. feel slightly
   d. rarely feel any

3. In noisy situations (e.g., a crowded restaurant or bar), I ________ more difficult to understand the speech of those sitting next to me than when in quiet situations.

   a. find it much
   b. find it somewhat
   c. find it slightly
   d. rarely find it any
4. I usually find high levels of background noise, like those encountered in a crowded restaurant or bar, to be...
   a. extremely bothersome
   b. very bothersome
   c. somewhat bothersome
   d. slightly bothersome
   e. rarely bothersome

5. I consider myself to be...
   a. extremely intolerant of background noise
   b. very intolerant of background noise
   c. somewhat intolerant of background noise
   d. slightly intolerant of background noise
   e. very tolerant of background noise

6. I...
   a. usually avoid situations that have high levels of background noise
   b. frequently avoid situations that have high levels of background noise
   c. sometimes avoid situations that have high levels of background noise
   d. occasionally avoid situations that have high levels of background noise
   e. rarely base my decision on whether to enter an environment on the level of the background noise

Questionnaire participants:
- 86 normal-hearing
- 53 hearing-impaired

Questionnaire results:
A regression analysis showed that the primary factors influencing listeners' ANLs were:
- Perceived concentration levels
- Perceived speech understanding abilities
- Perceived tolerance for background noise

NH: Coefficient of determination (R²) = .1627 (F4,81 = 5.3, p < .005)
HI: Coefficient of determination (R²) = .1861 (F4,48 = 3.7, p < .05)
**QUESTIONNAIRE RESULTS**  
Recker et al. 2011

- Can these results be used to predict the ANL category to which someone belongs?
- We performed a quadratic discriminant analysis (QDA)
- The ANL category to which an individual belonged could be predicted:
  - 54% of the time for normal-hearing
  - 49% of the time for hearing-impaired
  - Chance performance was 33%
  - Not good enough to be clinically useful

**QUESTIONNAIRE STUDY #2**  
Nichols and Gordon-Hickey, 2012

- Compared ANLs with results of a Self Control Scale (SCS)
- SCS
  - 36-items
  - 5-point scale ("not at all" to "very much")
- Results
  - Listeners who had more self control accepted higher levels of background noise ($r = -.28, p = .018$)

**LOUDNESS?**

- Are listeners basing their ANLs on the loudness of the background noise?

**ABOUT LOUDNESS**

- With the ANL test, speech and noise are presented at the same time
- The presence of one sound affects one’s judgment of the loudness of a 2nd sound
  - This is called “partial loudness” (Moore et al., 1997)

**ABOUT PARTIAL LOUDNESS**

A sound will sound louder when it occurs in isolation than when it occurs at the same time as other sounds.

**ABOUT PARTIAL LOUDNESS**

If the other sounds are relatively low in level, the sound that is higher in level will approach the loudness of that sound in quiet, and the loudness of the sounds that are lower in level will approach zero.
**Partial Loudness**

Having other sounds present can never increase the loudness of the 1st sound, it can only decrease it.

**Loudness Study**

- With the ANL test, we had to consider how the presence of the speech affects listeners' judgments of the loudness of the background noise.
- Most studies on partial loudness have used simple stimuli (tones, complex tones and narrow-band noise).

**Loudness Participants**

- 21 normal-hearing
- 21 hearing-impaired
- 7 in each of the ANL groups
  - Low (ANL < 7 dB)
  - Mid (ANL 7-13 dB)
  - High (ANL > 13 dB)

**Loudness Methods**

- **Reference Noise**
  - Arizona Travelogue
  - Cosmos Dist. Inc. (nd)

- **Speech + Noise**
  - 85 dB
  - 50 dB speech

  "Adjust the loudness of the background noise in "B" to match the loudness of the background noise in "A""
**Loudness Methods**

Reference Noise: 85 dB

Speech + Noise: 50 dB speech, 85 dB noise

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**Partial Methods**

Reference Noise: 85 dB

Speech + Noise: 50 dB speech, 85 dB noise

The speech is too low in level to affect the listener’s judgment of the loudness of the noise.

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**Loudness Results**

Reference Noise: 85 dB

Speech + Noise: 50 dB speech, 85 dB noise

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**Loudness Results**

Reference Noise: 85 dB

Speech + Noise: 50 dB speech, 85 dB noise

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**Loudness Results**

Reference Noise: 85 dB

Speech + Noise: 75 dB speech, 84 dB noise

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**Loudness Results**

Reference Noise: 85 dB

Speech + Noise: 88 dB speech, 83 dB noise

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Reference Noise: 85 dB
Loudness Matching for Noise

Reference Noise
Speech + Noise

75 dB

50 dB speech
74 dB noise

85 dB

Reference noise level (dBA)

NH; n = 21

Recker et al. in press

Loudness Matching for Noise

Reference Noise
Speech + Noise

75 dB

50 dB speech
74 dB noise

75 dB

63 dB speech
75 dB noise

75 dB

65 dB

88 dB speech
74 dB noise

65 dB

50 dB speech
74 dB noise

Recker et al. in press
The speech was loud enough that listeners perceived the noise as being softer. To compensate for this, they had to increase the level of the noise to make it equally loud as the reference noise.

Recker et al. in press

Loudness Matching for Noise

Reference Noise

Speech + Noise

Loudness Results

Recker et al. in press

55 dB

Reference Noise

Speech + Noise

45 dB

Reference Noise

Speech + Noise

30 dB

Reference Noise

Speech + Noise

HI; n = 21

NH; n = 21
ANLs and Loudness

- If listeners were using the loudness of the BGN as a listening cue, we would expect the loudness of the BGN to stay the same across multiple test levels.
- ANLs were tested with the speech fixed at 50, 63, 75 & 88 dBA.

Loudness Results

- 2/42 participants’ ANLs were consistent with a loudness-based listening strategy.
- What about the other 40 participants?

Loudness Summary

- Are listeners were adjusting the level of the speech/noise to reach a certain level of intelligibility across multiple test levels?

Speech Intelligibility

- Others found this too: Tampas & Harkrider, 2006; Freyaldenhoven et al, 2007; Recker & Edwards, 2013.
**SPEECH INTELLIGIBILITY**  
Recker et al. in press

Others found this too: Tampas & Harkrider, 2006; Recker & Edwards, 2013

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**SPEECH INTELLIGIBILITY**  
Valentine, 2009

Spectra of the background noise stimuli

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**SPEECH INTELLIGIBILITY**  
Valentine, 2009

5 people with low ANLs

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**SPEECH INTELLIGIBILITY**  
Valentine, 2009

Average ANL Scores

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**SPEECH INTELLIGIBILITY**  
Recker and Edwards, in preparation

- SII (Speech Intelligibility Index)
- Scores: 0 to 1
- SII scores were calculated for each test condition

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**SII Values**  
Valentine, 2009

- Broadband
- Lowpass
- Highpass
- LF Bandpass
- HF Bandpass
- Babble
**SPEECH INTELLIGIBILITY**

Recker and Edwards, in preparation

- SII scores were calculated for each participant/test level
- SII's that varied by < .1 across test conditions were considered consistent with a speech-intelligibility-based listening criteria

**SPEECH INTELLIGIBILITY RESULTS**

Recker and Edwards, in preparation

- Results were consistent with a speech-intelligibility-based listening cue for:
  - ~62% of normal-hearing (4 low, 3 mid and 6 high ANLS)
  - ~5% of hearing-impaired (1 mid ANL)

Why the discrepancy?

**SPEECH INTELLIGIBILITY RESULTS**

Recker and Edwards, in preparation

- Speculation
  - Those with low ANLS may be choosing the lowest SNR that provides good speech intelligibility
  - Those with mid and high ANLS may also be minimizing listening effort
  - Sato et al. (2011) found that speech intelligibility is maximized at ~0 dB SNR, but listening effort is not minimized until the SNR is ~10-15 dB

**SPEECH INTELLIGIBILITY RESULTS**

Recker and Edwards, in preparation

- Speculation
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**SPEECH INTELLIGIBILITY RESULTS**

Recker and Edwards, in preparation

- Hearing-impaired listeners' results were more variable
  - Extreme example—speech intelligibility estimated at:
    - 10% speech at 50 dBA
    - 100% speech at 88 dBA
  - Median improvement was 49%
    - Participants didn't follow instructions?
    - SII not accurate for ANL stimuli?
    - Transfer function for changing SIIs into percent correct inaccurate?
**SPEECH INTELLIGIBILITY RESULTS**

Recker and Edwards, in preparation

- Speculation
  - Extremely low SII for hearing-impaired listeners suggest that SII may not be an accurate predictor of speech intelligibility for the ANL
  - Follow-up testing should be performed using a speech-intelligibility test at listeners' ANLs

**OTHER THOUGHTS ON SPEECH INTELLIGIBILITY**

- If listeners were using speech intelligibility to determine their ANLs, one would expect hearing-aid features that:
  - Improve speech intelligibility (e.g. directional microphones, remote microphones) should lower ANLs
  - Do not improve speech intelligibility (e.g. noise reduction) should have no effect on ANLs

**OTHER THOUGHTS ON SPEECH INTELLIGIBILITY**

- Directional Microphones
  - 2.8-4.9 dB improvement in ANL
    (Freyaldenhoven et al, 2005; Peeters et al, 2009; Kim and Bryan, 2011; Wu and Stangl, 2013)
  - Improvement similar to speech-in-noise tests
    (Freyaldenhoven et al, 2005; Peeters et al, 2009; Kim and Bryan, 2011)

**OTHER THOUGHTS ON SPEECH INTELLIGIBILITY**

- Noise Reduction (NR)
  - Benefit is inconsistent
    - 0-4.2 dB
      (Mueller et al, 2006; Peeters et al, 2009; Fredelake et al, 2012; Wu and Stangl, 2013)
  - Higher ANLs have greater benefit

**ANLS AND NOISE REDUCTION**

Edwards et al, 2011

Those who are the least likely to be successful with hearing aids are most likely to experience improvements in ANL with NR

- If using loudness (or annoyance, listening effort, etc.), NR may improve the ANL
- If using speech intelligibility as a cue, no benefit would be expected (NR can’t improve intelligibility)

Eddins and Klein et al (2013) found similar results

**SUMMARY**

- Many studies out there
  - Many of them have conflicting results
  - Differences in study design
  - Test-retest
  - Population differences?
**Summary**

- Knowing why people are willing to accept the BNLs that they do may provide insight into what’s going on
  - People likely using different cues
  - Possibly using multiple cues at once

- Questionnaires
  - Mild, but significant correlations between listeners’ ANLs and:
    - Perceived concentration levels (Recker et al, 2011)
    - Perceived speech understanding abilities (Recker et al, 2011)
    - Self-reported tolerance for background noise (Recker et al, 2011)
    - Self-control (Nichols and Gordon-Hickey, 2012)
  - Loudness
    - 2/42 ANLs were consistent with a loudness-based listening criteria (Recker et al, in press)
  - Speech intelligibility (SII)
    - Suggested that 62% of normal-hearing participants and 5% of hearing-impaired participants may have used speech intelligibility as a cue for determining their ANL (Recker and Edwards, in preparation)

- Other cues
  - Annoyance
  - Listening effort
  - Other?

**Summary**

- Various technologies can reduce ANLs
  - For those who are at risk for being unsuccessful with hearing aids, you may want to consider:
    - Directional microphones (Freyaldenhoven et al, 2005; Peeters et al, 2005; Kim and Bryan, 2011; Wu and Stangl, 2013)
    - Remote microphones
    - Increase the strength
    - Less gain for loud sounds?

**Quiz Q4 (Not Covered)**

- Listeners’ tolerated SNRs:
  - Vary depending on the instructions
  - Are the same regardless of whether the listener adjusts the level of the speech or the level of the background noise
  - Are the same as ANLs
  - “b” and “c” are correct

**Questions/Comments?**
REFERENCES

• Cosmas Dist. Inc. (nd) Quality recordings for the hearing health care industry. Kalamza, B.C.

REFERENCES

• Recker K and Edwards, in preparation.