ACCEPTABLE NOISE LEVELS
A USEFUL TOOL?

Karrie Recker, AuD
Senior Research Audiologist

Starkey

CAN YOU HEAR ME?

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MUST SUCCESSFULLY COMPLETE A SHORT QUIZ.

ACCEPTABLE NOISE LEVELS
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WHAT IS ACCEPTABLE NOISE LEVEL (ANL)?

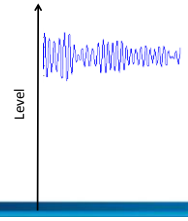
- The highest level of background noise someone is "willing to put up with" while listening to speech

WHY ARE ANLS IMPORTANT?

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

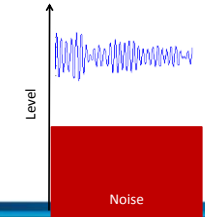
MEASURING ANLS

- Listener adjusts speech to a comfortable level



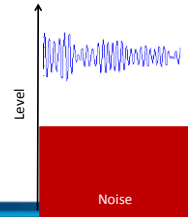
MEASURING ANLS

- Background noise is added



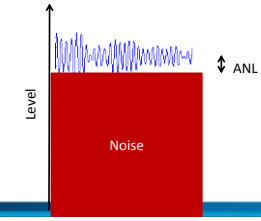
MEASURING ANLS

- Listener adjusts the noise to her max tolerable level



MEASURING ANLS

ANL = speech level - noise level

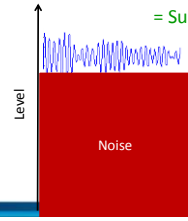


MEASURING ANLS

Small ANL (willing to listen at poor SNRs)

= Successful HA user

(Nabelek et al., 2006)

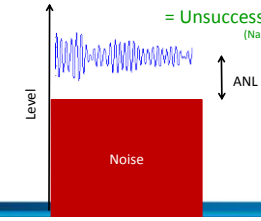


MEASURING ANLS

Large ANL (want to listen at high SNRs)

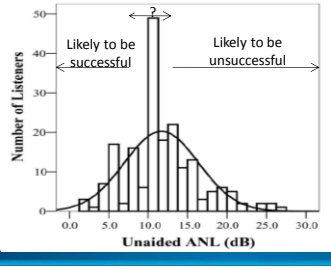
= Unsuccessful HA user

(Nabelek et al., 2006)



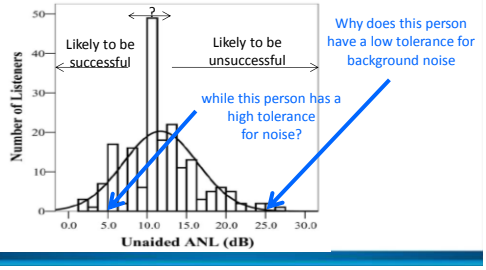
Distribution of ANLs

Nabelek et al., 2006



Distribution of ANLs

Nabelek et al., 2006



ANLs

- 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: General Information

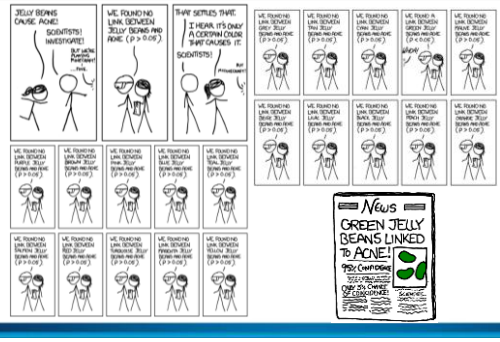
- ANLs are not related to:
  - An individual's age (Nabelek et al, 1991)
  - Locus of control (Nichols and Gordon-Hickey, 2012)
  - Interest level of the material (Plyler et al, 2011)

ANLs: General Information

- There is conflicting evidence regarding whether ANLs are related to:
  - Speaker gender (Plyler et al, 2011; Gordon-Hickey et al, 2012)
  - Listener gender (Rogers et al, 2003; Gordon-Hickey et al, 2012)
  - Hearing sensitivity (Nabelek et al, 1991; Fredelake et al, 2012)
  - 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)

variable	doesn't matter	it matters
speaker gender	Plyler et al. 2011	ANLs lower w/female talker (Gordon-Hickey et al. 2012)

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?

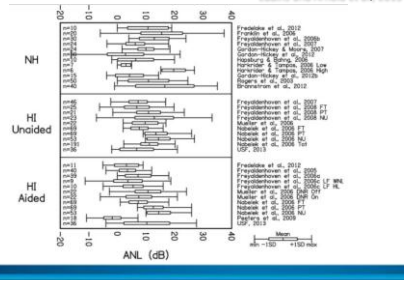
Experimenter?
Study participant?

WHY THE CONFLICTING RESULTS?

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

DISTRIBUTION OF ANLS

Eddins and Arnold et al., 2013

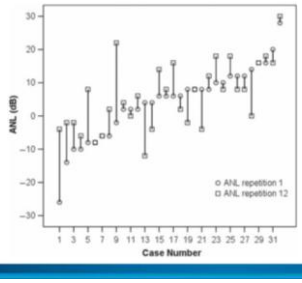


WHY THE CONFLICTING RESULTS?

- 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?

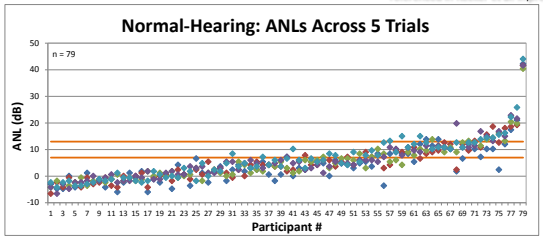
TEST-RETEST

Brännström et al., 2013



TEST-RETEST

raw data
referenced in Recker et al. *in press*



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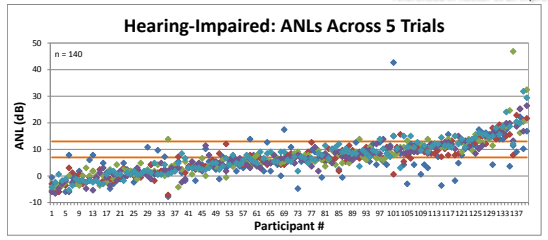


WHAT DOES ALL OF THIS MEAN?

SUMMARY

- 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

TIME TO CHANGE OUR PERSPECTIVE?

TIME TO CHANGE OUR PERSPECTIVE?

- 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)

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?

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

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

Questionnaire

Recker et al. 2011

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

Questionnaire

Recker et al. 2011

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

QUESTIONNAIRE

Recker et al. 2011

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

QUESTIONNAIRE

Recker et al. 2011

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

QUESTIONNAIRE

Recker et al. 2011

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

Recker et al. 2011

- 86 normal-hearing
- 53 hearing-impaired

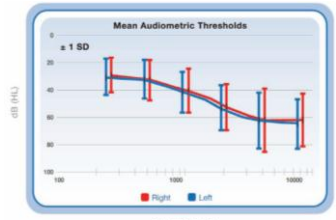


Figure 1. Mean audiometric thresholds ± 1 standard deviation (SD).

QUESTIONNAIRE ANLS

Recker et al. 2011

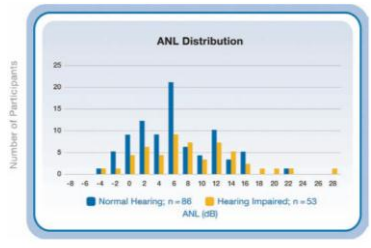


Figure 2. Distribution of ANLs for normal-hearing and hearing-impaired participants.

QUESTIONNAIRE RESULTS

Recker et al. 2011

- A regression analysis showed that the primary factors influencing listeners' ANLs were:
  - Perceived concentration levels
  - Perceived speech understanding abilities HI
  - Perceived tolerance for background noise NH
    - NH: Coefficient of determination (R^2) = .1627 ($F_{4,81} = 5.3$, $p < .005$)
    - HI: Coefficient of determination (R^2) = .1861 ($F_{4,48} = 3.7$, $p < .05$)

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 ($r = -.28$, $p = .018$)

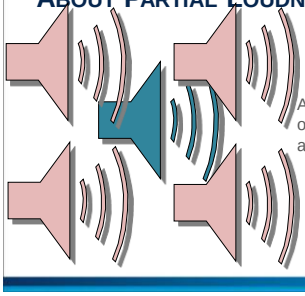
Loudness?

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

About Loudness

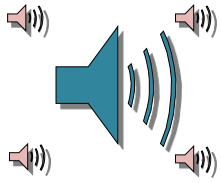
- With the ANL test, speech and noise are presented at the same time
- The presence of one sound affects one's judgment of the loudness of a 2nd sound
  - This is called "partial loudness" (Moore et al., 1997)

About Partial Loudness



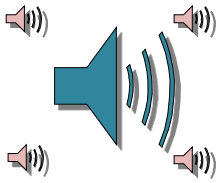
A sound will sound louder when it is occurs in isolation than when it occurs at the same time as other sounds

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

About Partial Loudness



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

Loudness Study

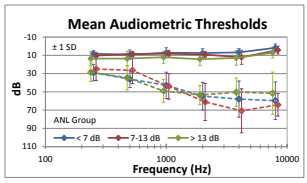
Recker et al. *in press*

- 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

Recker et al. *in press*

- 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)

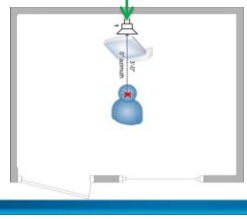


Loudness Methods

Recker et al. *in press*

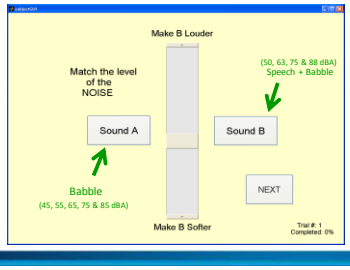
Arizona Travelogue
Cosmos Dist. Inc. (nd)

speech
noise
multi-talker babble



Loudness Methods

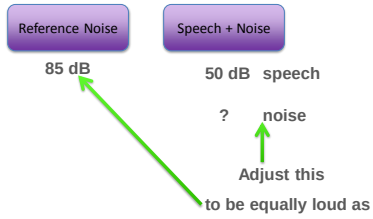
Recker et al. *in press*



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

Loudness Methods

Recker et al. *in press*



Loudness Methods

Recker et al. *in press*

Reference Noise | Speech + Noise

85 dB = 50 dB speech

85 dB noise

Partial Methods

Recker et al. *in press*

reference | test

noise | noise

speech

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

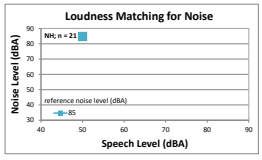
Loudness Results

Recker et al. *in press*

Reference Noise | Speech + Noise

85 dB = 50 dB speech

85 dB noise



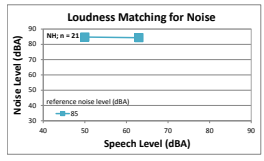
Loudness Results

Recker et al. *in press*

Reference Noise | Speech + Noise

85 dB ≈ 63 dB speech

84 dB noise



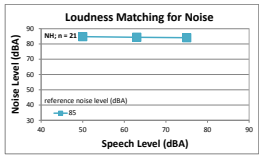
Loudness Results

Recker et al. *in press*

Reference Noise | Speech + Noise

85 dB ≈ 75 dB speech

84 dB noise



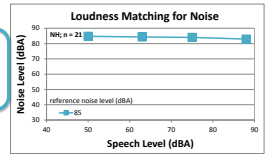
Loudness Results

Recker et al. *in press*

Reference Noise | Speech + Noise

85 dB ≈ 88 dB speech

83 dB noise



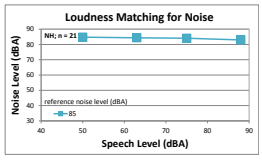
LOUDNESS RESULTS

Recker et al. *in press*

Reference Noise | Speech + Noise

75 dB ≈ 50 dB speech

? noise



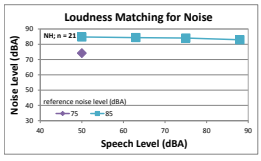
LOUDNESS RESULTS

Recker et al. *in press*

Reference Noise | Speech + Noise

75 dB ≈ 50 dB speech

74 dB noise



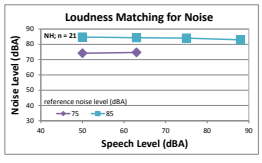
LOUDNESS RESULTS

Recker et al. *in press*

Reference Noise | Speech + Noise

75 dB ≈ 63 dB speech

75 dB noise



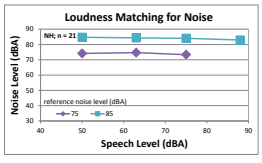
LOUDNESS RESULTS

Recker et al. *in press*

Reference Noise | Speech + Noise

75 dB ≈ 75 dB speech

73 dB noise



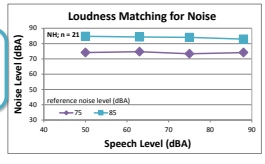
LOUDNESS RESULTS

Recker et al. *in press*

Reference Noise | Speech + Noise

75 dB ≈ 88 dB speech

74 dB noise



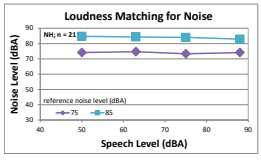
LOUDNESS RESULTS

Recker et al. *in press*

Reference Noise | Speech + Noise

65 dB ≈ 50 dB speech

? noise



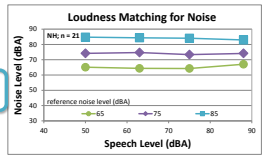
LOUDNESS RESULTS

Recker et al. *in press*

Reference Noise | Speech + Noise

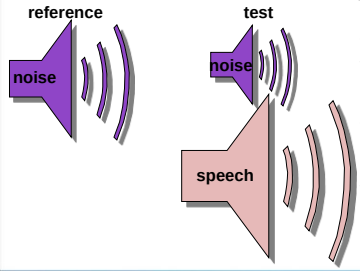
65 dB ≈ 88 dB speech

67 dB noise



PARTIAL LOUDNESS

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

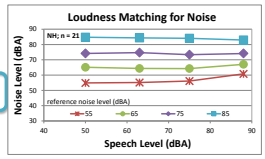
LOUDNESS RESULTS

Recker et al. *in press*

Reference Noise | Speech + Noise

55 dB ≈ 88 dB speech

61 dB noise



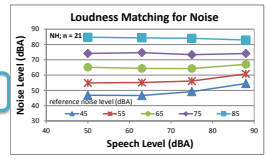
LOUDNESS RESULTS

Recker et al. *in press*

Reference Noise | Speech + Noise

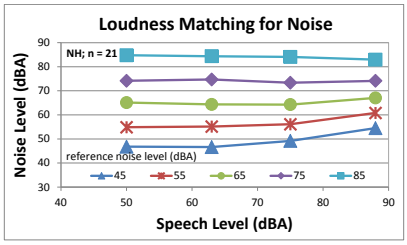
45 dB ≈ 88 dB speech

55 dB noise



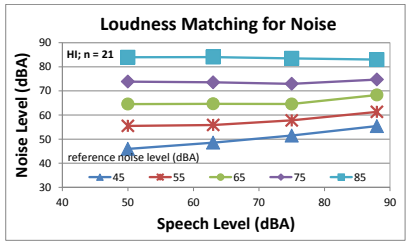
LOUDNESS RESULTS

Recker et al. *in press*



LOUDNESS RESULTS

Recker et al. *in press*



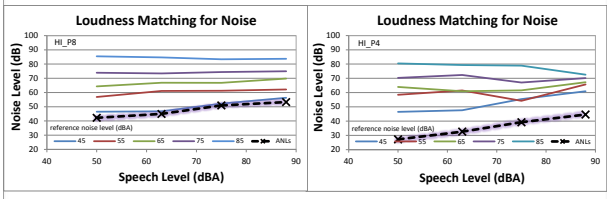
ANLs and Loudness

Recker et al. *in press*

- 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 w/the speech fixed at 50, 63, 75 & 88 dBA

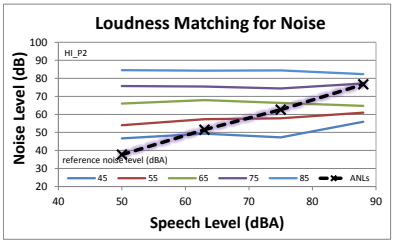
Loudness Results

Recker et al. *in press*



Loudness Results

Recker et al. *in press*



Loudness Summary

Recker et al. *in press*

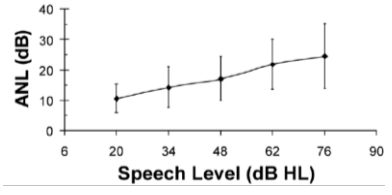
- 2/42 participants' ANLs were consistent with a loudness-based listening strategy
- What about the other 40 participants?

Speech Intelligibility?

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

Speech Intelligibility

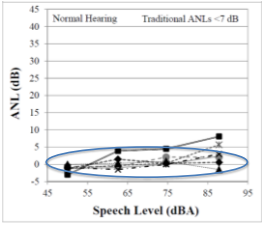
Franklin et al., 2006



Others found this too: Tampas & Harkrider, 2006; Freyaldenhoven et al, 2007; Recker & Edwards, 2013

SPEECH INTELLIGIBILITY

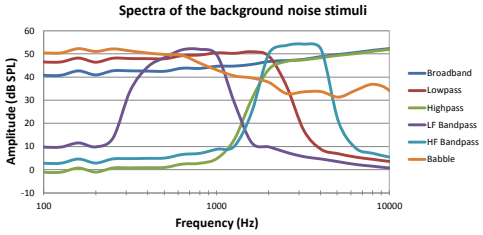
Recker et al. *in press*



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

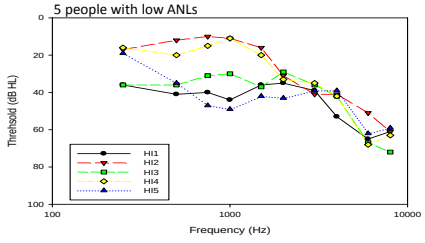
SPEECH INTELLIGIBILITY

Valentine, 2009



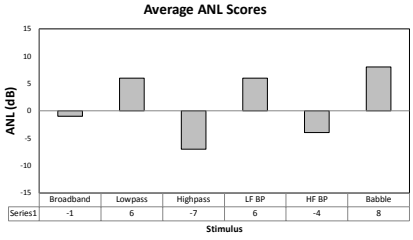
SPEECH INTELLIGIBILITY

Valentine, 2009



SPEECH INTELLIGIBILITY

Valentine, 2009



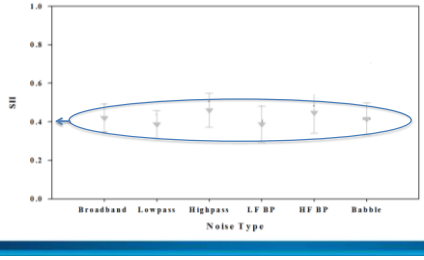
SPEECH INTELLIGIBILITY

Recker and Edwards, *in preparation*

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

SIIs

Valentine, 2009



SII AND INTELLIGIBILITY

Hargus and Gordon-Salant, 1995

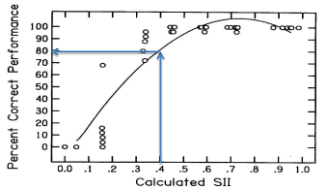


FIGURE 3. Normal transfer function relating SII to performance for the R-SPIN (PH) stimuli, including data from YN subjects.

HI listeners on average set the background noise to achieve ~ 80% intelligibility

SPEECH INTELLIGIBILITY

Recker and Edwards, *in preparation*

- SII scores were calculated for each participant/ test level
- SIIs 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*

Normal-Hearing	ANL Group			
Mean	Low	Mid	High	
ANL	.3	13.6	12.3	Large ANL differences
SII	.46	.82	.79	Large SII differences
% correct*	88%	~100%	~100%	Similar Speech Intelligibility

*Estimated using Figure 3 from Hargus and Gordon-Salant (1995)

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*

- 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 SIIs 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

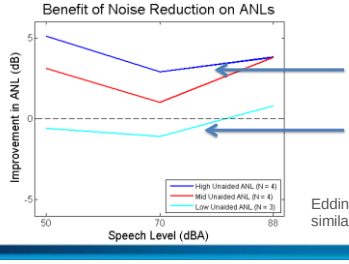
- Directional Microphones
  - 2.8-4.9 dB improvement in ANL (Freyaldenhoven et al, 2005; Peeters et al, 2009; Kim and Bryan, 2011; Wu and Stangl, 2013)
    - Improvement similar to speech-in-noise tests (Freyaldenhoven et al, 2005; Peeters et al, 2009; Kim and Bryan, 2011)

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 (Mueller et al, 2006; Eddins and Klein et al, 2013; Edwards et al, 2013)

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

SUMMARY

- 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*)

SUMMARY

- 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, 2009; Kim and Bryan, 2011; Wu and Stangl, 2013)
    - Remote microphones
  - Noise reduction (Mueller et al, 2006; Peeters et al, 2009; Fredelake et al, 2012; Eddins and Klein et al, 2013; Edwards et al, 2011; Wu and Stangl, 2013)
    - 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?

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THANK YOU

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