THE MULTI-FACETED COMPLEXITY OF SPEECH IN NOISE UNDERSTANDING AND TECHNOLOGICAL SOLUTIONS

Brent Edwards[1]
Director, National Acoustic Laboratories
Sydney, Australia

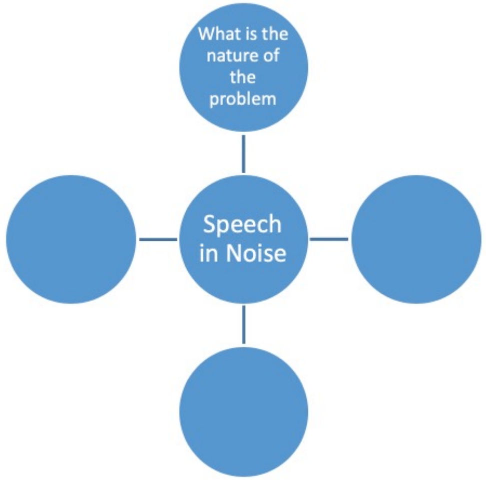
[1] Adjunct Professor, Macquarie University

Hearing Aid Technology for Improving Speech in Noise

- Noise reduction
- Directional microphones
- Array processing (beamforming)
- Remote microphones
- Multiband compression
- Feedback cancellation
- Frequency lowering

The Speech in Noise Problem

Speech in Noise



Nature of the Speech in Noise Problem

Hearing loss Measure	% of Non-owners (n=4,209)	% of Owners (n=3,109)	Hearing Aid Adoption (%)
Ears impaired			
Uniteral loss	39	13	10
Bilateral loss	61	87	32
Perceived loss			
Mild	41	8	6
Moderate	46	52	27
Severe	10	36	55
Profound	2	4	38
Gallaudet Scale			
Hear whisper	17	7	12
Hearing normal speech	49	29	17
Hear shouts	29	49	36
Hear shout better ear	3	8	44
Tell speech from loud noise or worse	2	7	54
Difficulty hearing in noise			
Extremely difficult	11	36	53
Quite difficult	23	30	32
Somewhat difficult	35	25	19
Slightly difficult	25	8	10
Not at all difficult	6	1	8

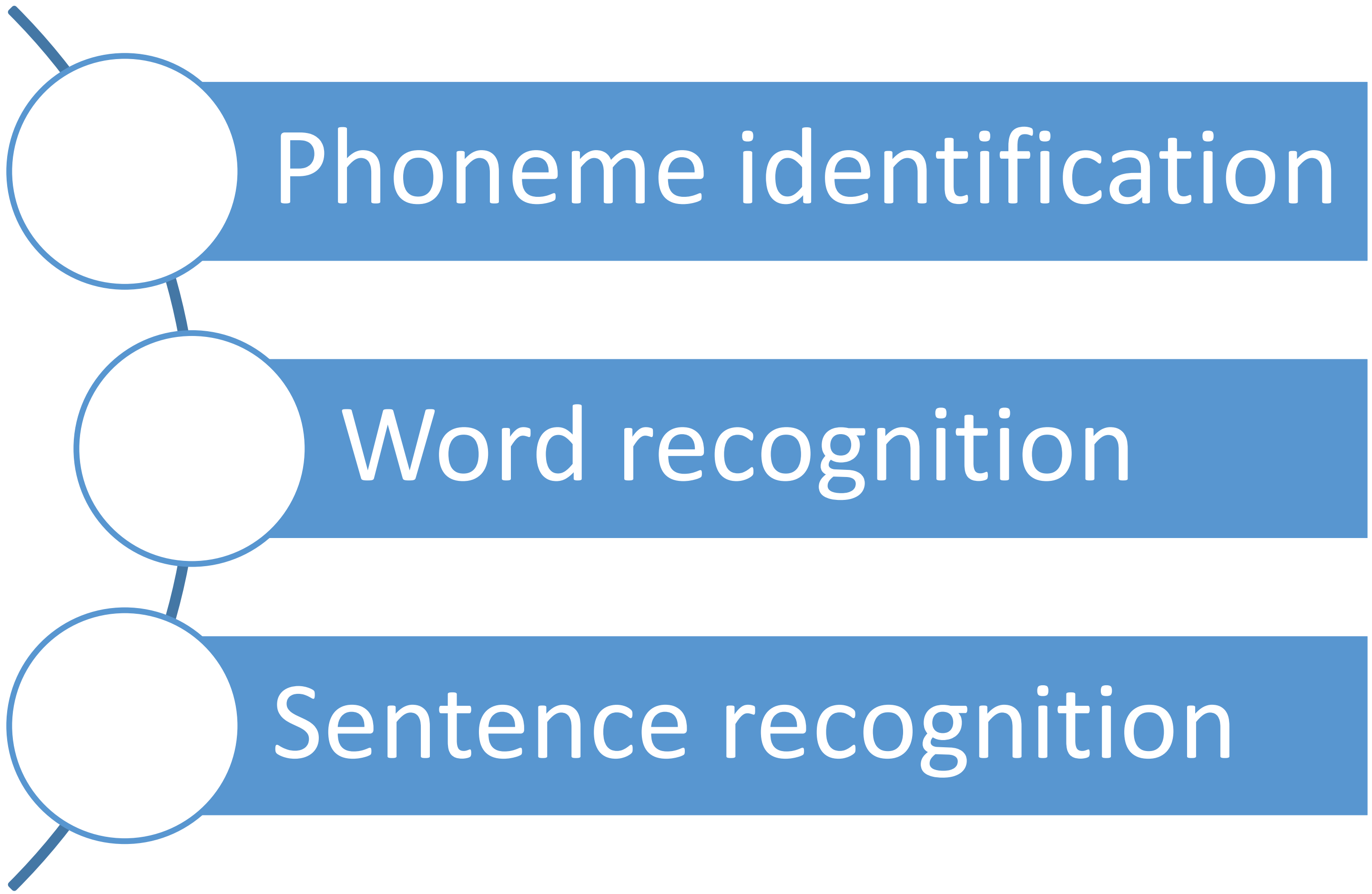
Marketrak 7, 2009

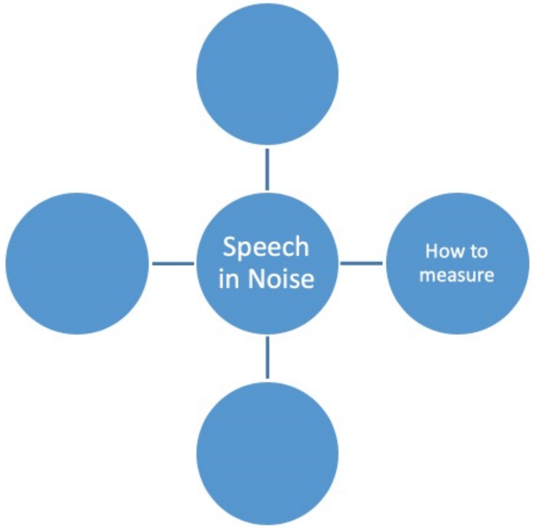
Conversations in Noise the Main Complaint

Top-3 Box Satisfaction small samples in some cells – use caution	**Owners:**		**Non-Owners:**	
	HA <=5 years (n=769)	**HA 6+ years** (n=112)	**Returners** *Who Tried HA* (n=44)	**Never Owned** (n=2055)
Overall, across all listening situations	80%	67%	55%	42%
In conversations with 1 person	88%	79%	53%	62%
In the workplace	83%	70%	66%	46%
At home with family members	82%	74%	56%	49%
In conversations with small groups	81%	67%	54%	46%
When listening to music	80%	69%	55%	53%
When watching TV with others	79%	68%	56%	40%
During leisure activities (e.g., exercising, taking a walk, etc.)	78%	66%	57%	53%
Outdoors	78%	65%	54%	49%
In a store, when shopping	76%	62%	57%	46%
At a movie theater	75%	70%	62%	53%
When riding in a car	75%	69%	51%	46%
In a larger lecture hall (e.g., theater, concert hall, place of worship, etc.)	73%	59%	62%	38%
When talking to children	72%	67%	55%	42%
In conversations with large groups	71%	57%	54%	28%
When talking on a cell phone	70%	59%	50%	47%
When talking on a traditional telephone	69%	59%	52%	51%
In a classroom (as observer or student)	68%	58%	76%	37%
When trying to follow conversations in the presence of noise (e.g., restaurant, etc.)	67%	50%	51%	25%

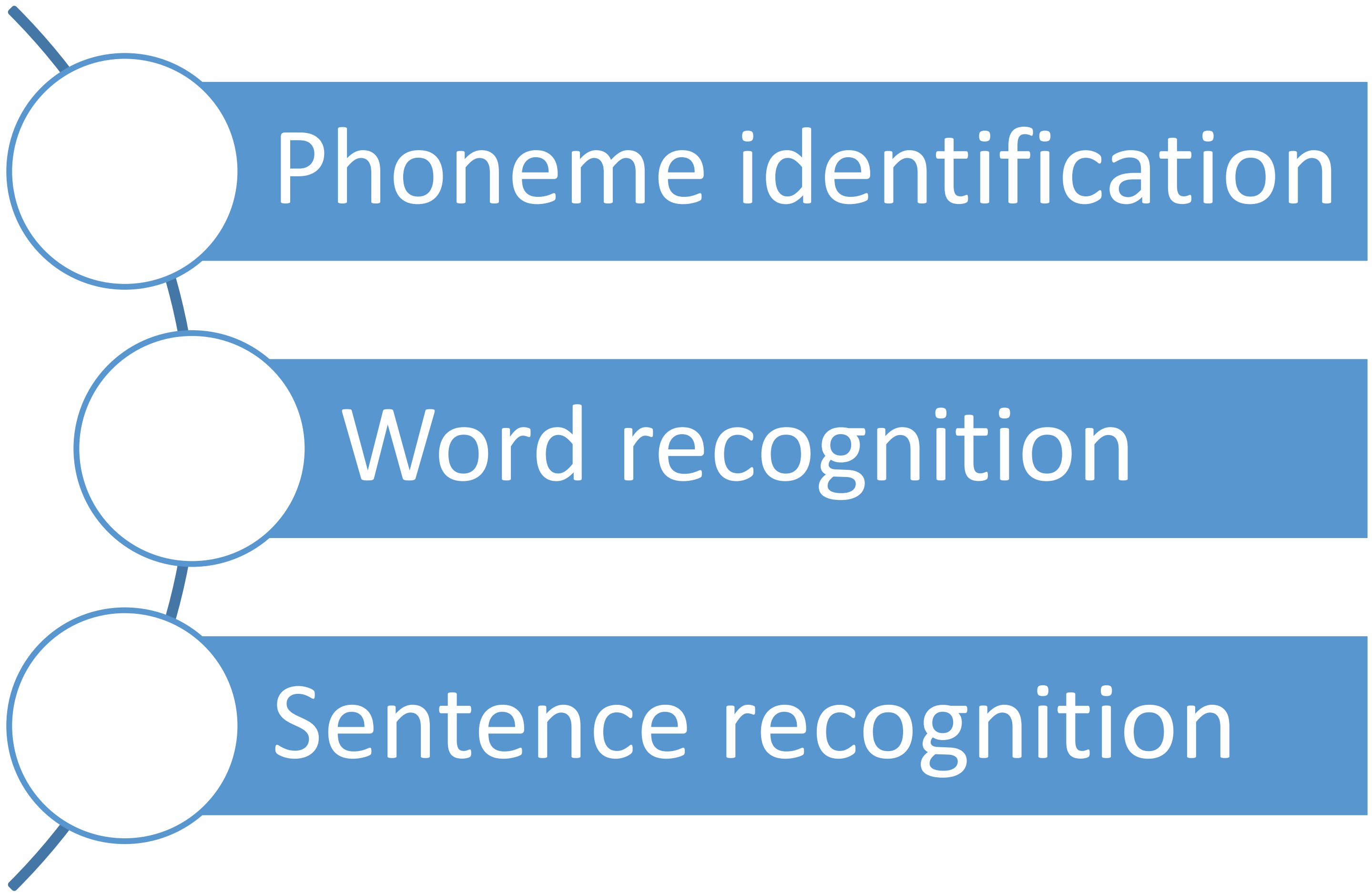
Marketrak 9, 2015

What is the nature of the difficulty?


Phoneme identification
Word recognition
Sentence recognition



How to Measure Speech in Noise Difficulty


Phoneme identification
Word recognition
Sentence recognition

Laboratory performance not always the same as in the real world

72 SEMINARS IN HEARING/VOLUME 26, NUMBER 2 2005

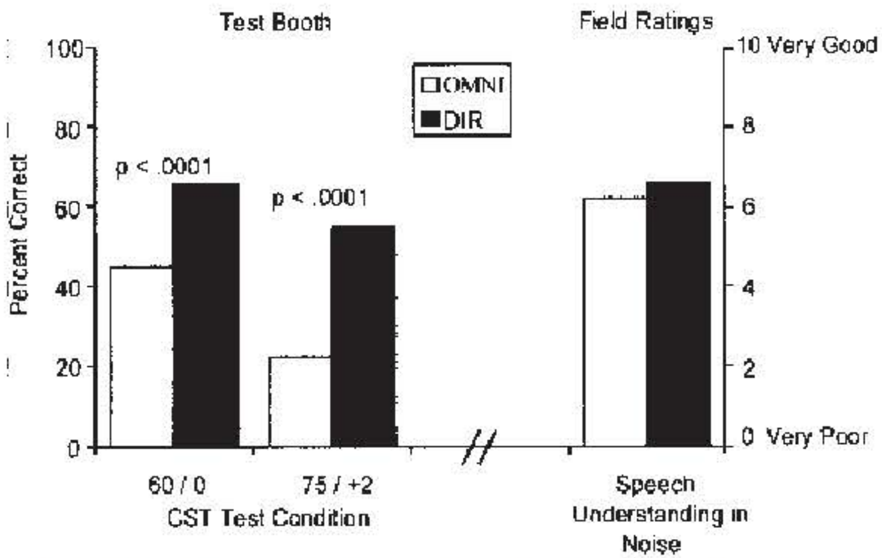
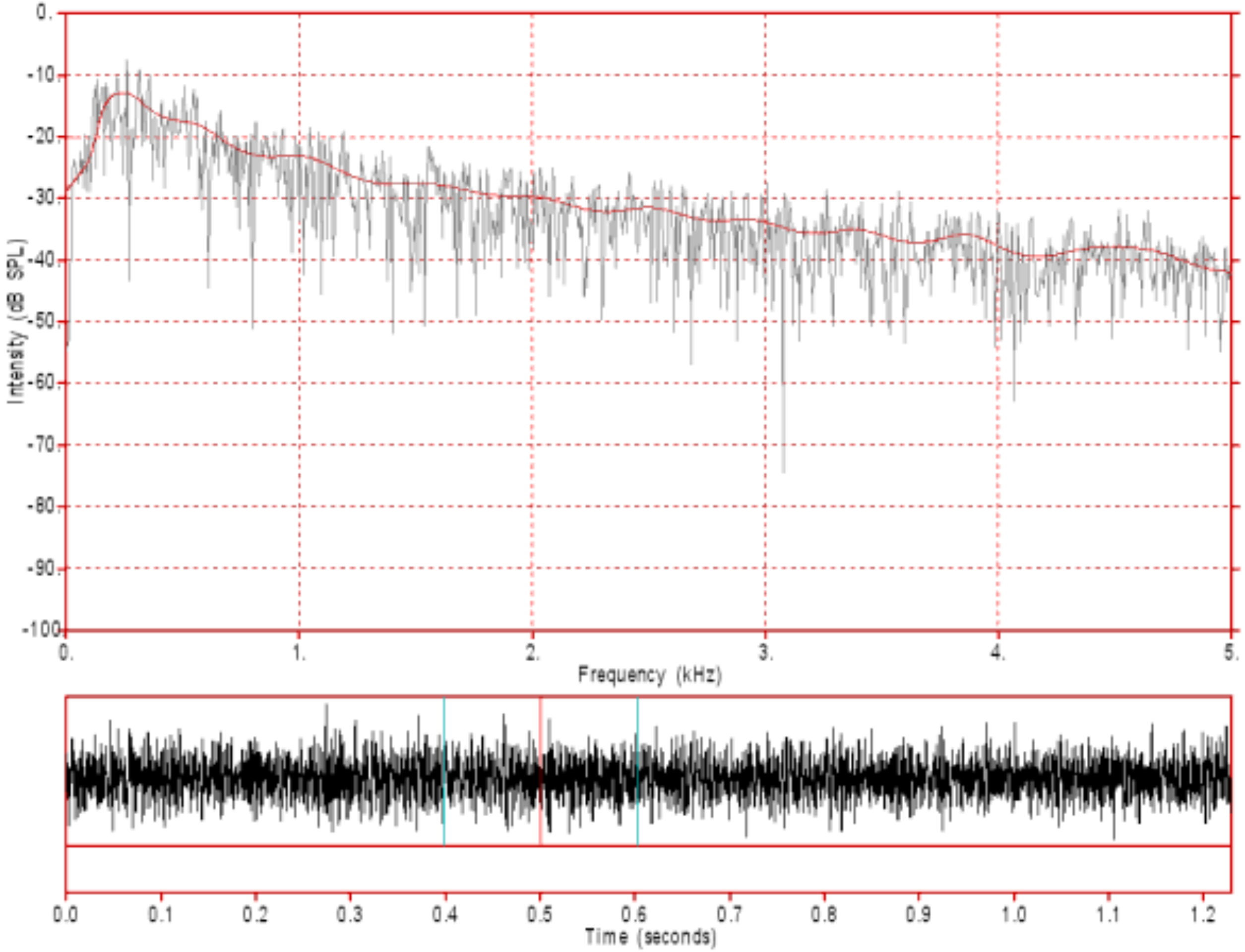
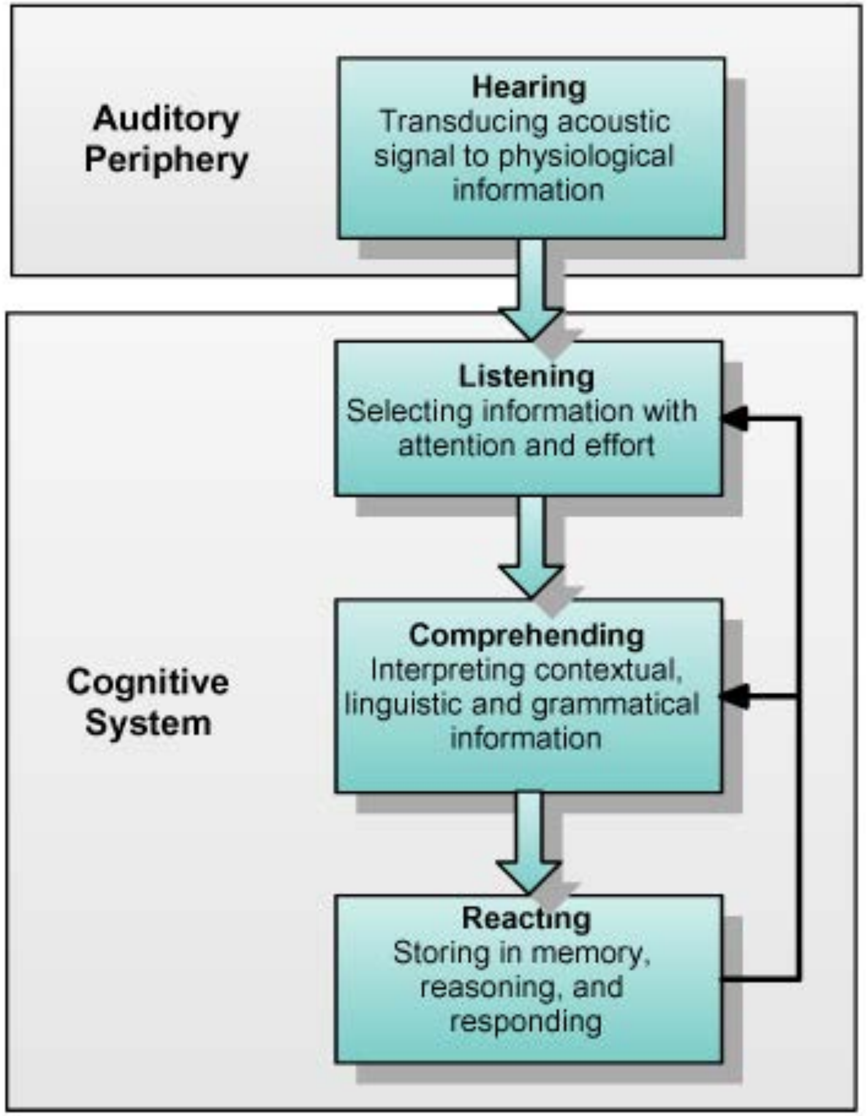


Figure 1 Comparison of (left) the directional advantage obtained in an audiometric test booth under two test conditions to (right) field ratings of speech understanding in background noise for the two microphone modes. OMNI, omnidirectional; DIR, directional.

Walden *et al.*, 2005

Speech-shaped noise





Edwards, 2007

Goal: Realism in Laboratory Testing

- Challenge is to make the testing situation as realistic as possible while also controlled and repeatable
  - Including access to all possible auditory cues available in real world

Spatial Hearing Technology

Environments	Positive References	
	CONV	SHA
One on one in quiet	9	12
Small group (~2-7 people)	8	7
Work	2	5
Restaurants	9	12
Crowds	4	13
Stores	1	4
Theater	5	5
Church or large room with microphone/s	13	7
Outside (Open Spaces)	5	2
Telephone	3	3
Electronic Speakers (Drive-Thrus)	1	1
TV	8	12
Bus	0	1
Car	5	8
Home Environmental Sounds	0	2
Singing		

Spatial Hearing Technology

- "I hear people talking and can tell where they are as I walk by even in traffic. It feels like I'm eavesdropping!"

Spatial Hearing Technology

- "I hear people talking and can tell where they are as I walk by even in traffic. It feels like I'm eavesdropping!"
- "I am better aware of sounds surrounding me."

Spatial Hearing Technology

- “I hear people talking and can tell where they are as I walk by even in traffic. It feels like I’m eavesdropping!”
- “I am better aware of sounds surrounding me.”
- “The evening at the bar Thursday night was great. The background noise was loud but I could hear as well as good hearing folk, and I didn't have to ask anyone to repeat a thing - how good is that!!!.”

Realistic Approach #1: Comprehension Task

The times were rough as I tried to establish myself in the field, but the projects were finally starting to pour in. Now I could finally enjoy some of the things I had always longed for, like building my dream house. But that night, though I was grateful to be there, I was more grateful that sleep was near [Q1].

Hafter *et al.*, 2012

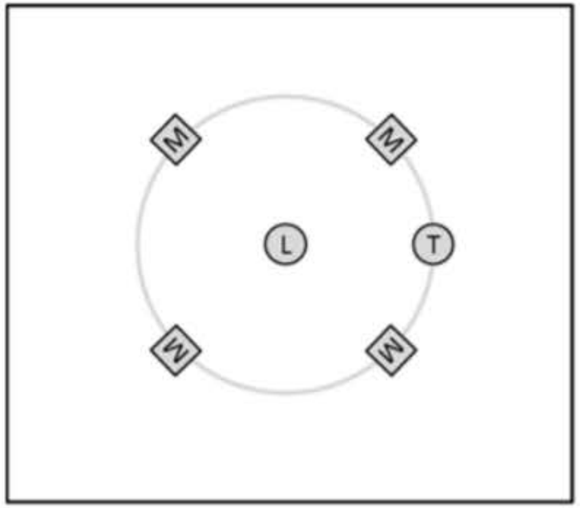
Realistic Approach #2: Ambisonics

- **Aim:** to determine whether introducing realistic aspects to speech tests can better capture individual differences and ultimately produce more relevant performance measures. Specifically, the examining the psychometric effects of:

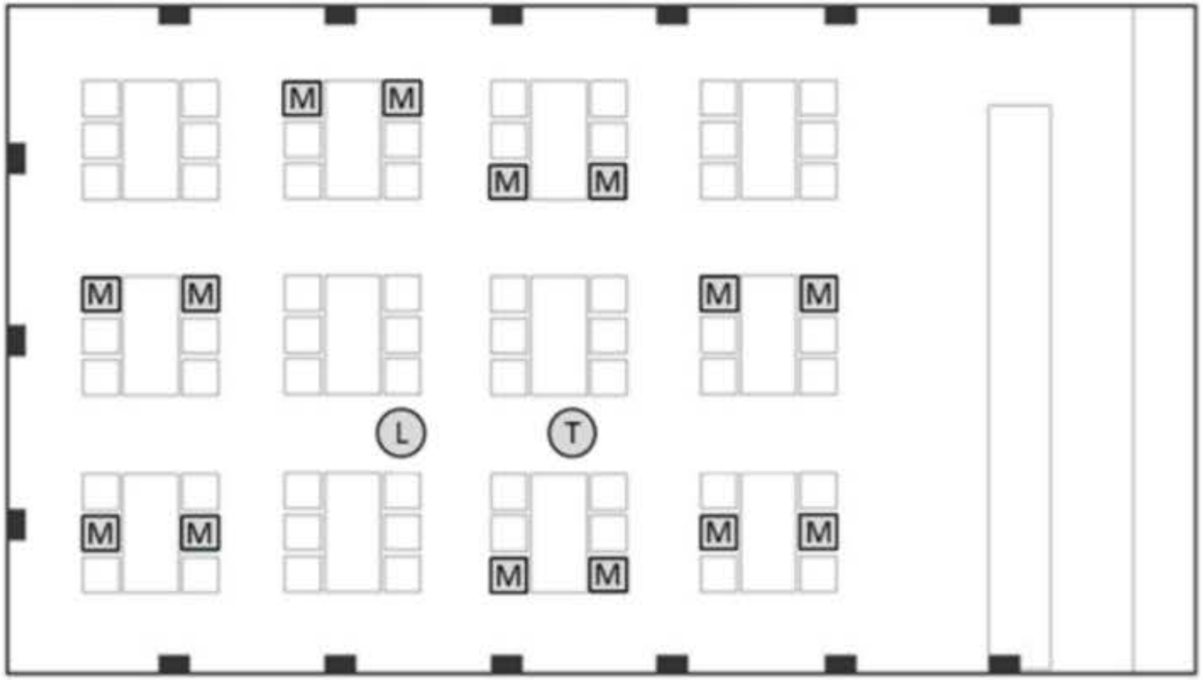
a) transplanting a standard sentence-in-noise test simulated reverberant cafeteria environment, and

b) moving from sentence recall to a new ongoing speech comprehension task.

Best *et al.*, 2013



The standard anechoic chamber, with a target (T) located directly in front of the listener (L), and four babble maskers (M) located at ±45° and ±135° azimuth.



The realistic reverberant cafeteria (HOA), with a frontal target and seven pairs of speech maskers located around the listener

Best *et al.*, 2013

Methods

Participants: N = 26. 18 NH + 28 HI with bilateral sensorineural hearing impairments (difference between the ears not greater than 25 dB)

Stimuli

Speech reception threshold (SRT): targets were Bamford-Kowal-Bench sentences spoken by an Australian male talker [Bench et al., 1979].

Comprehension: Targets were 2-4 min monologues spoken by the same talker using transcripts taken from the listening comprehension component of the International English Language Testing System (IELTS; Cambridge University Press)

Procedure

Estimate the individual 50% SRT , set this as the test SNR, as well as 2 dB above and below. Using these 3 SNRs estimate individual psychometric function and extract the 50% thresholds and slopes.

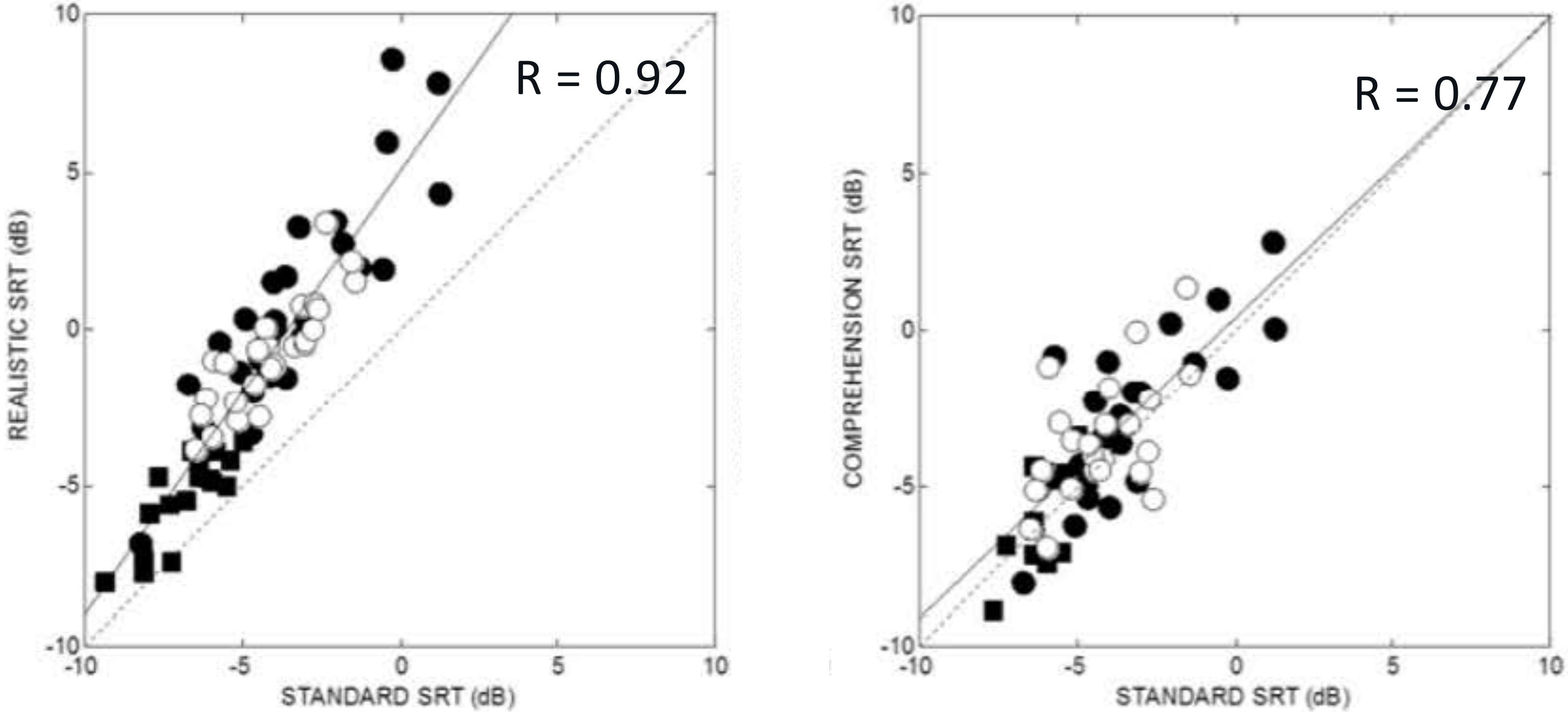
Best *et al.*, 2013

Outcomes

NH
(squares)

unaided HI
(filled circles)

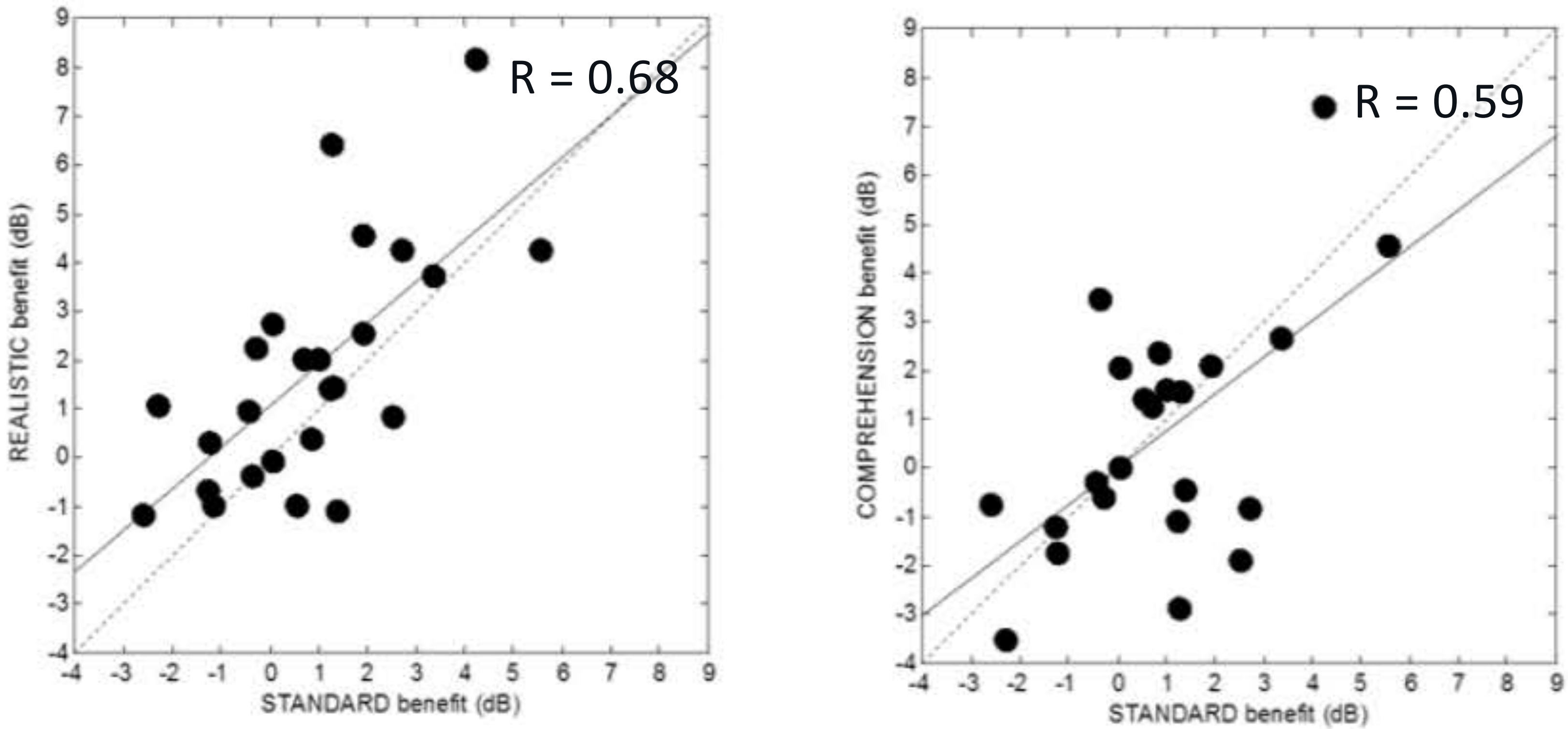
aided HI
(open circles).



Best *et al.*, 2013

Outcomes

Hearing aid benefits by subtracting unaided SRTs from aided SRTs.



Best *et al.*, 2013

What about measures other than understanding?

Why People Are Unhappy with Hearing Aids

- Too much background noise (30%)
- Not natural/distorted (17%)
- Did not work well enough/“right” (13%)
- Durability/reliability issues (breaks, constant repairs, etc.) (7%)
- Too loud/only amplifies (6%)
- Ears plugged/occluded (4%)
- Physically uncomfortable (4%)
- Caused infection (4%)
- HCP did not do what was necessary to get them to work right (4%)

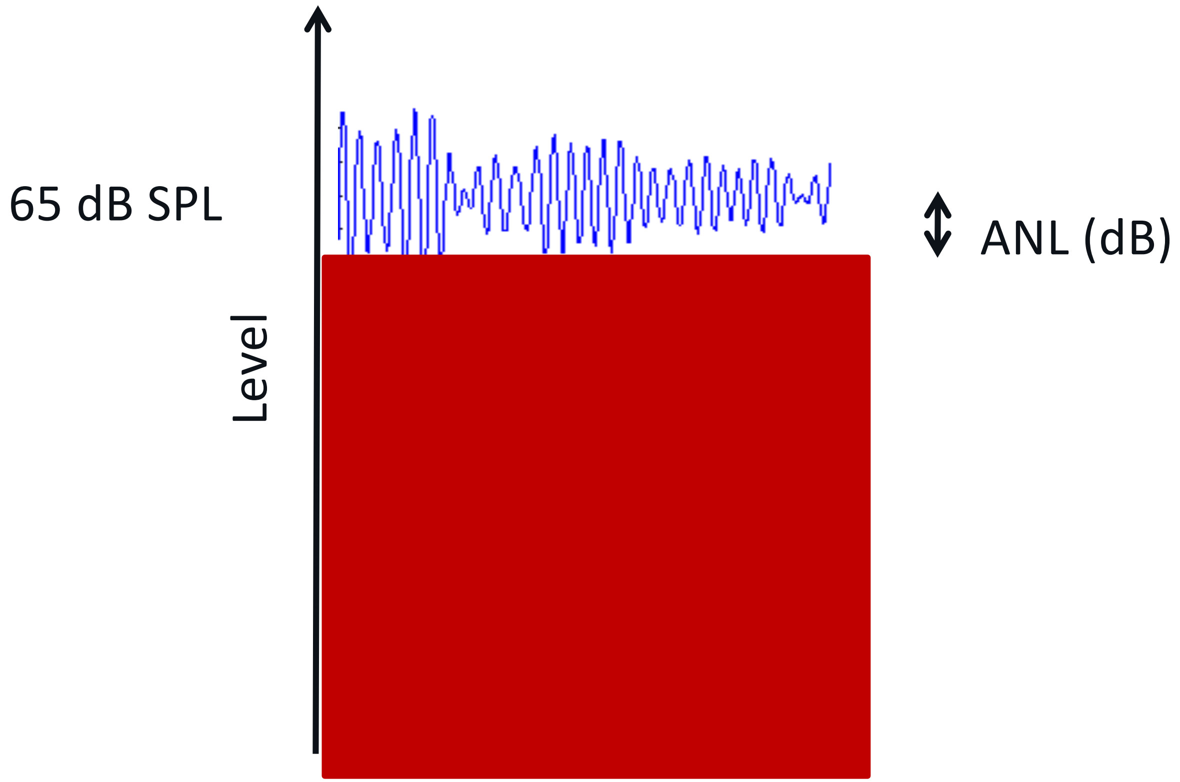
Marketrak 9, 2015

Alternatives to Understanding

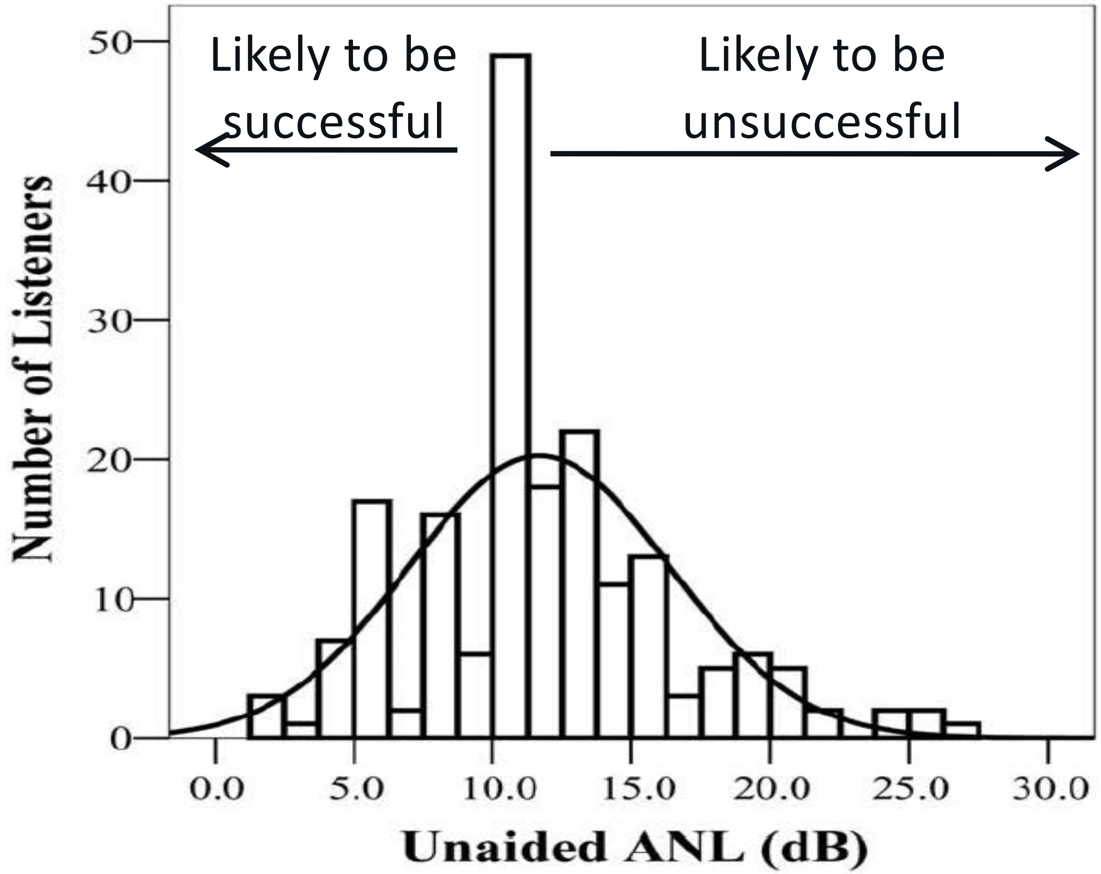
- Noise comfort

Measure of Noise Tolerance

Acceptable Noise Level (ANL)

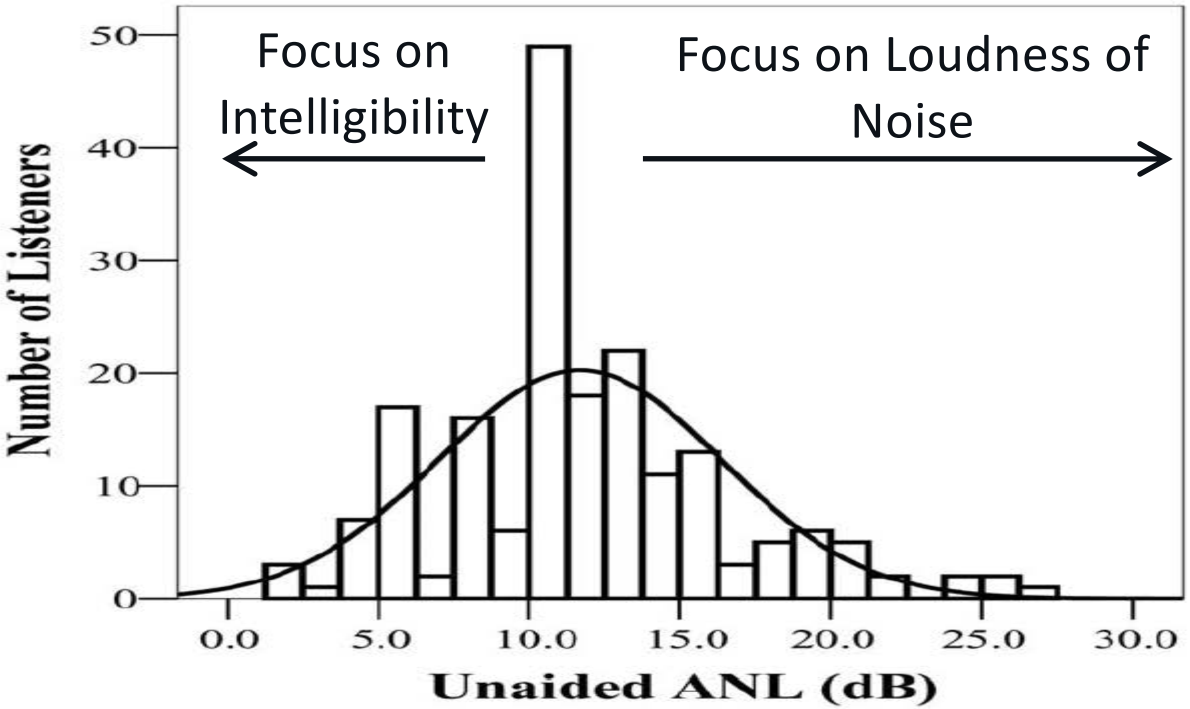


Acceptable Noise Level



Nabelek *et al.*, 2006

Acceptable Noise Level



Alternatives to Understanding

- Noise comfort
- Listening effort

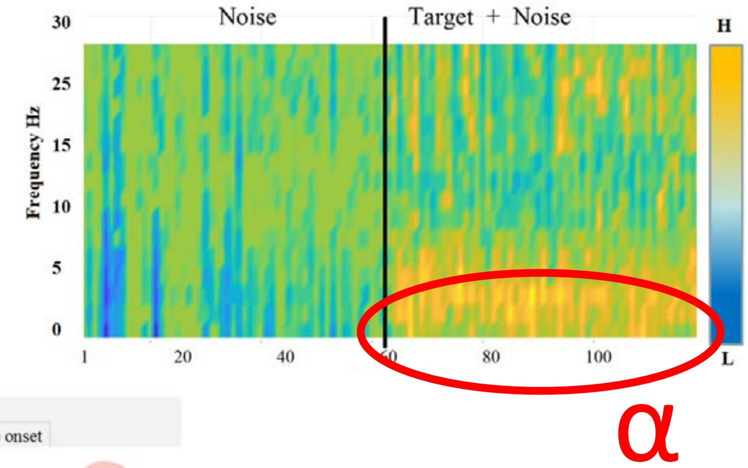
Listening Effort

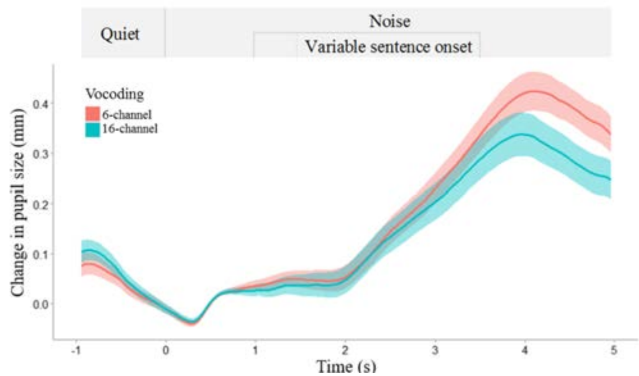
- What we mean by increased effort with speech in noise:
  - Increased cognitive load
  - Increased mental fatigue
  - Poorer auditory memory
  - Poorer auditory scene analysis
  - Difficult focusing

Measures of Listening Effort

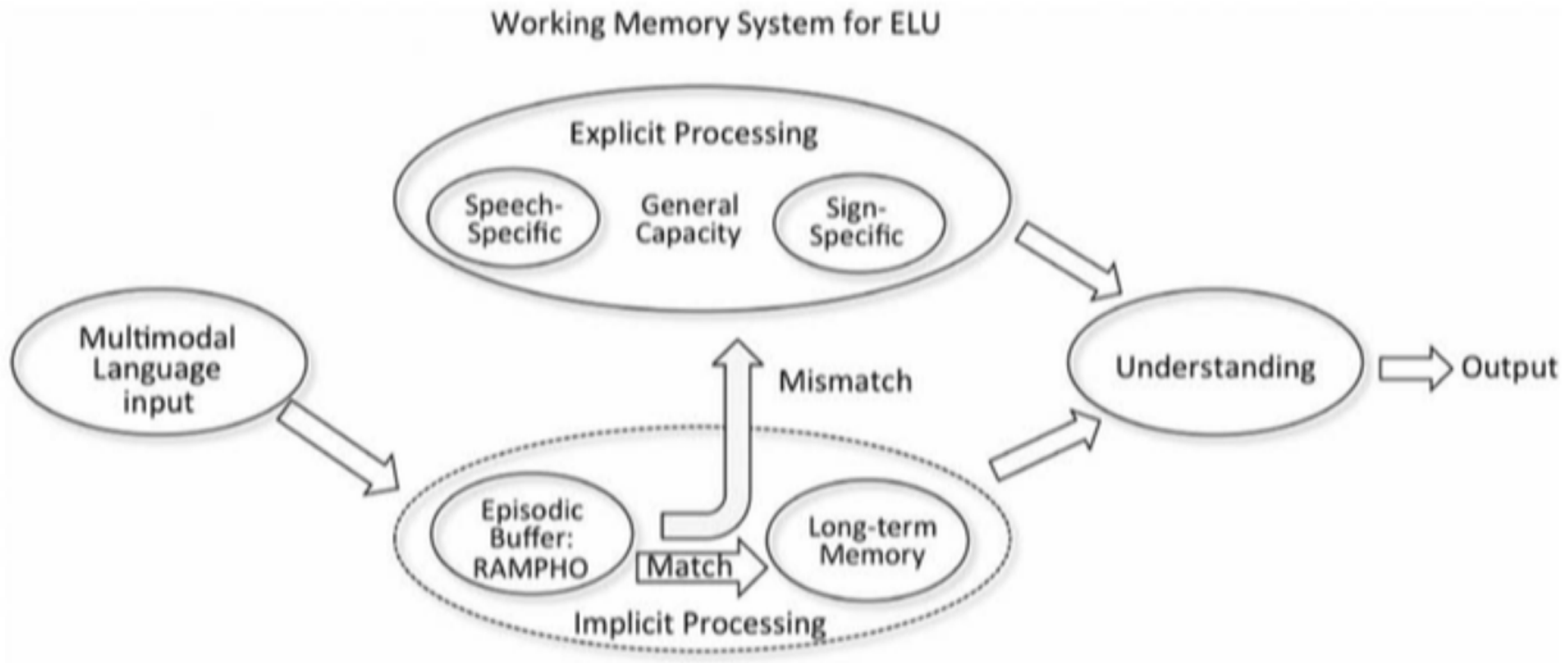
Measures of listening effort:

- Self-reported measures
- EEG measures
- Physiological measures (skin conductance, heart rate)
- Pupil dilation
- Behavioural tests





Ease of Language Understanding Framework



Rönnberg et al., 2008

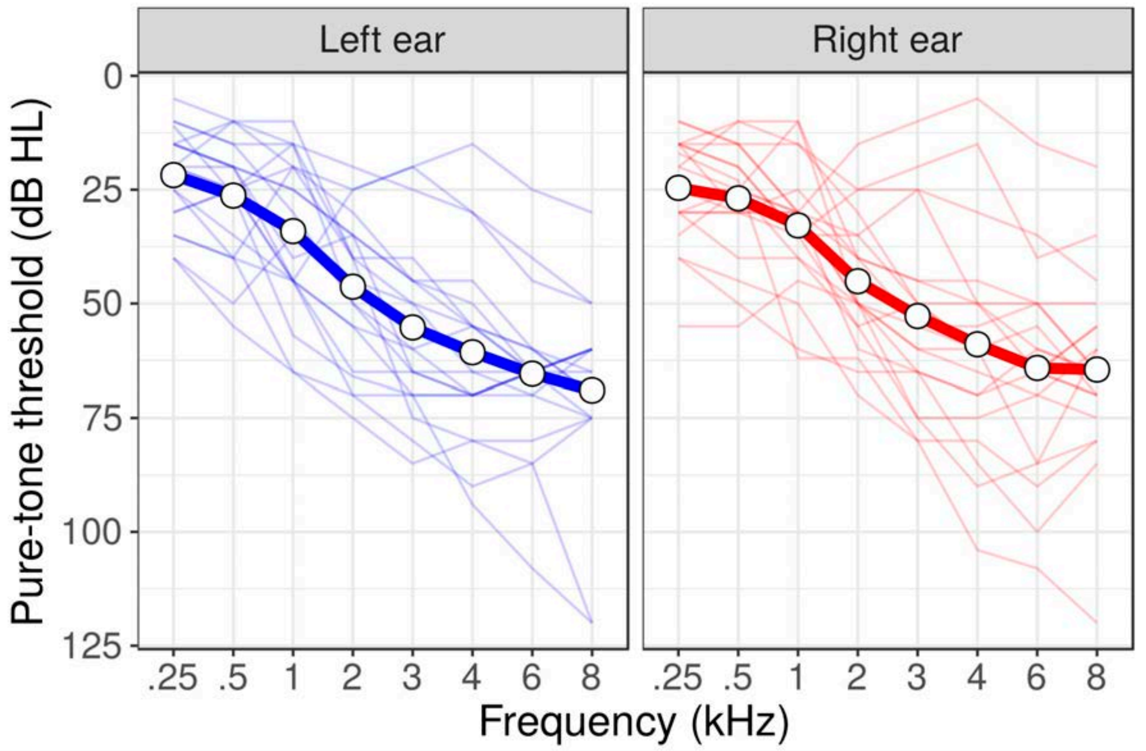
Alternatives to Understanding

- Noise comfort
- Effort
- Conversation Partner

What About the Conversation Partner?

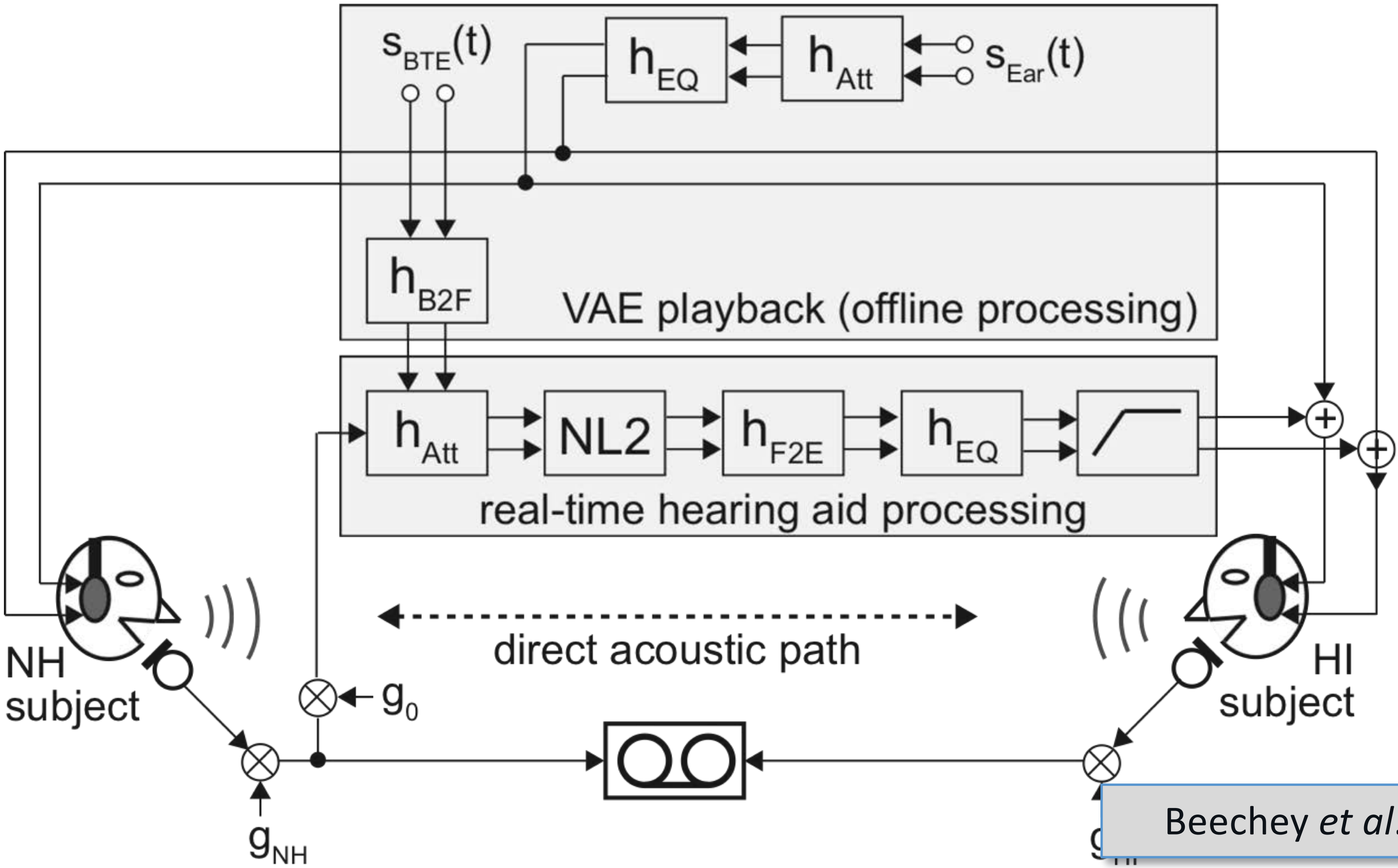
Participants

- 20 younger adult participants (13 female) aged 19-45 (mean=28.4, sd=6.9) with normal audiometric thresholds
- 20 older adults (6 female) aged 53-85 (mean=73.0, sd=7.4) with symmetrical SNHL.
- HI participants had 4FAHLs ranging from20-63.1 dB HL) (mean=41.2, sd=13.0)
- Participants were tested in pairs (1 NH with 1 HI participants)
- 5 realistic noise conditions
- 5 minute conversations were recorded in each noise condition
- The same participant pairing were used in both unaided and aided experiments



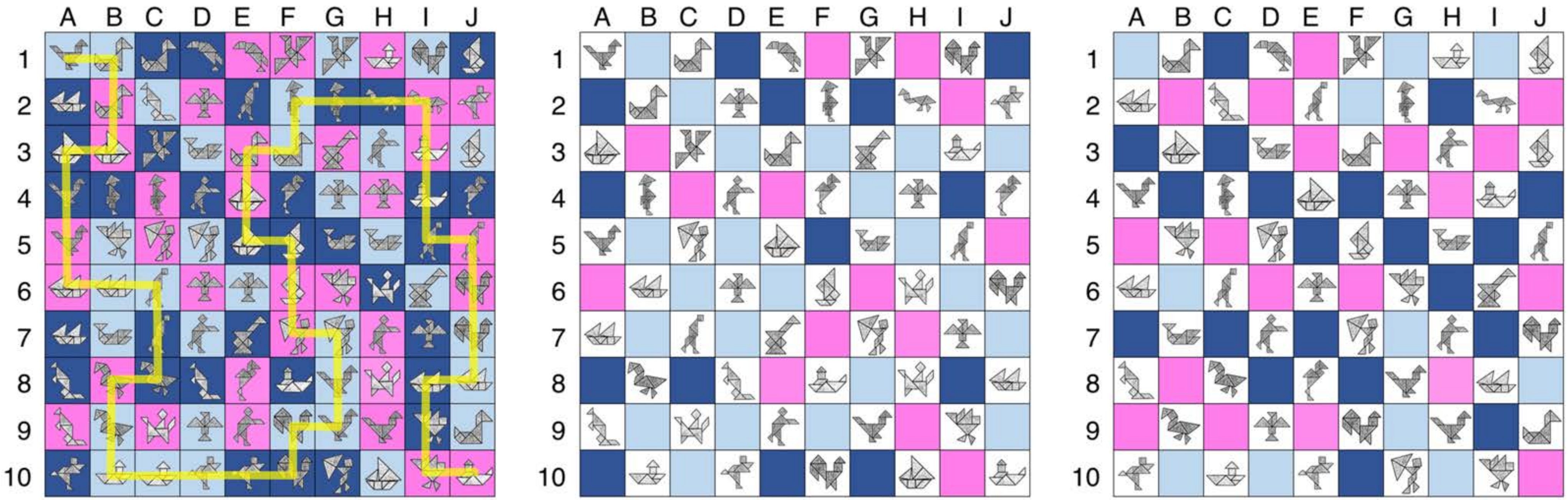
Beechey *et al.*, In Review

Experiment Setup



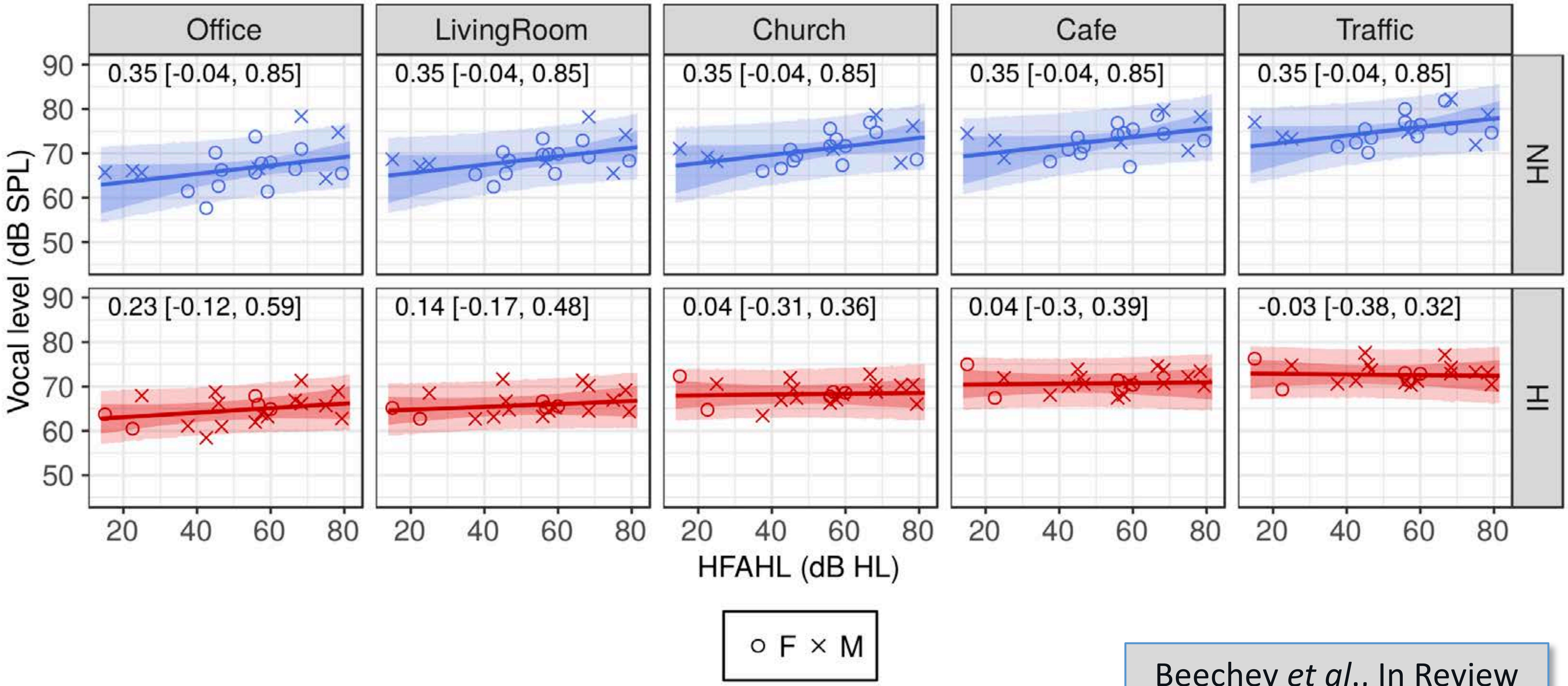
Beechey *et al.*, In Review

Conversation Elicitation Task



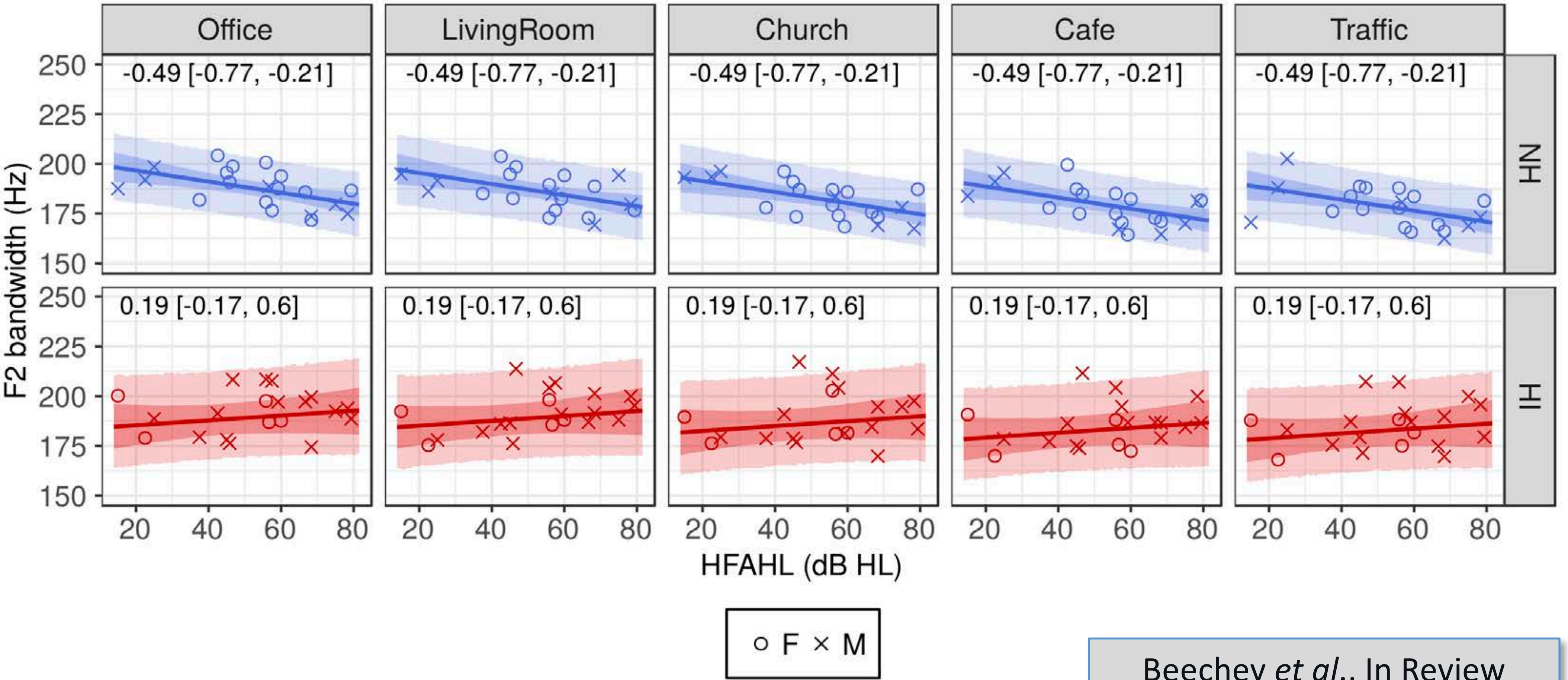
Beechey *et al.*, In Review

NH talker vocal level with with unaided conversation partner



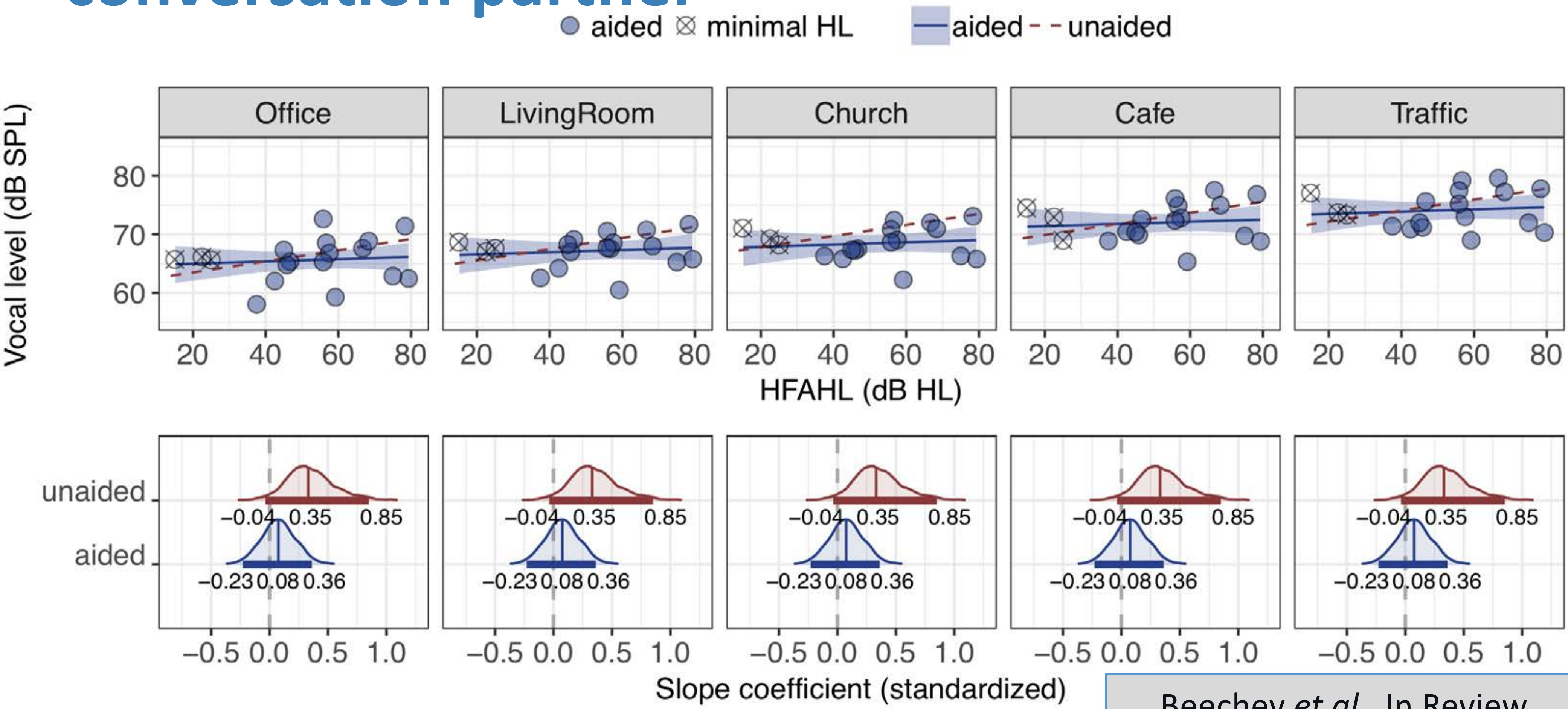
Beechey *et al.*, In Review

NH talker F2 bandwidth with with unaided conversation partner



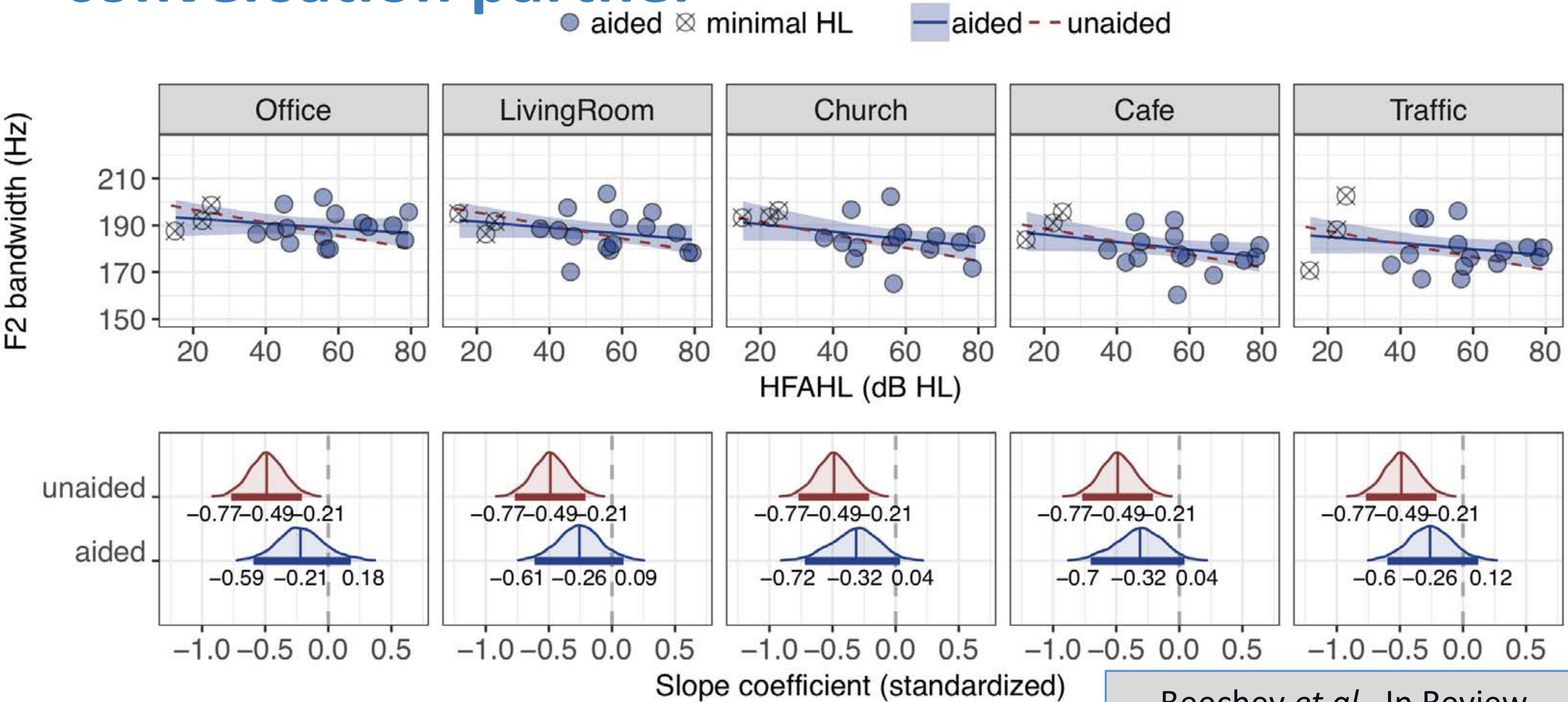
Beechey *et al.*, In Review

NH talker vocal level with with aided conversation partner



Beechey *et al.*, In Review

NH talker F2 bandwidth with with aided conversation partner



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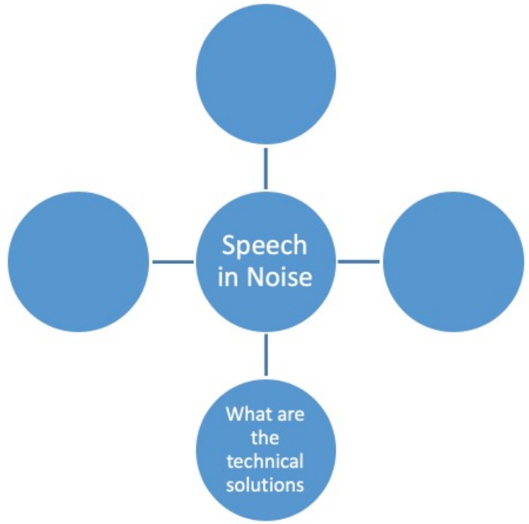
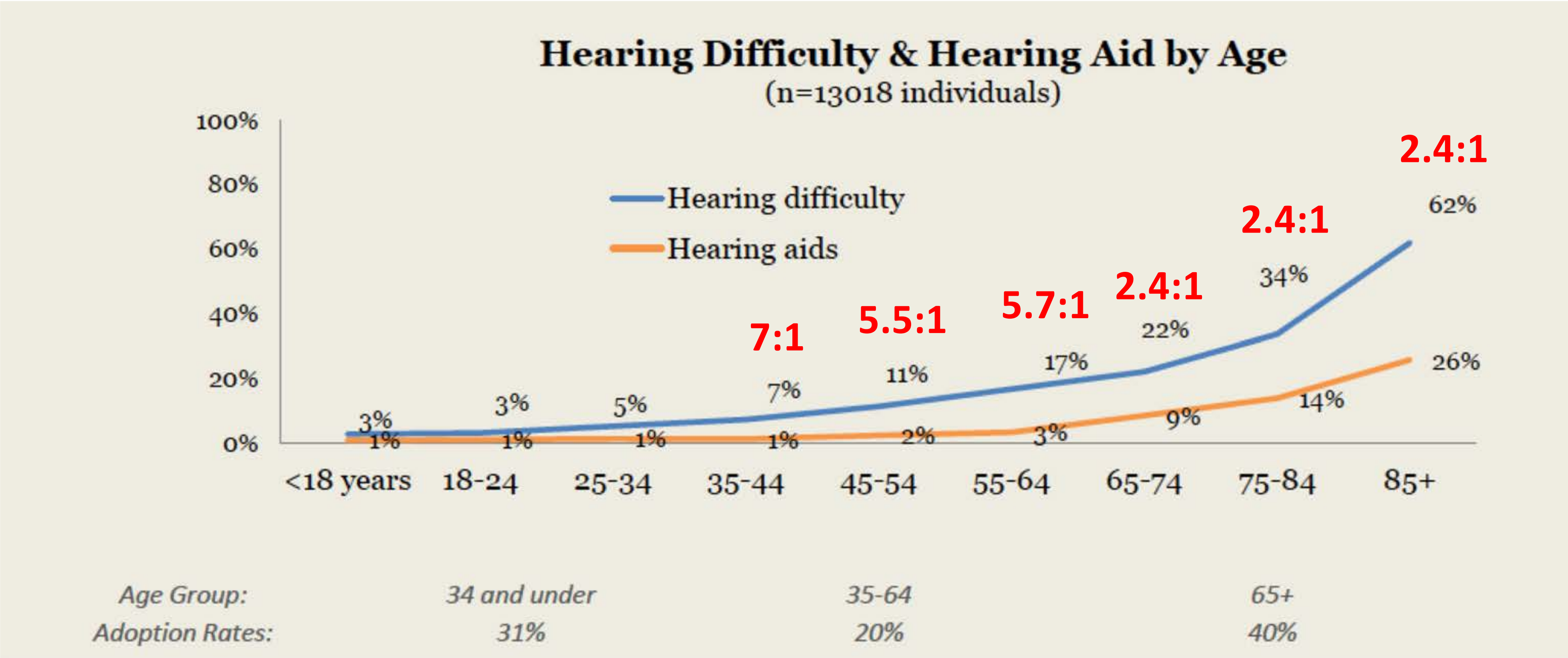
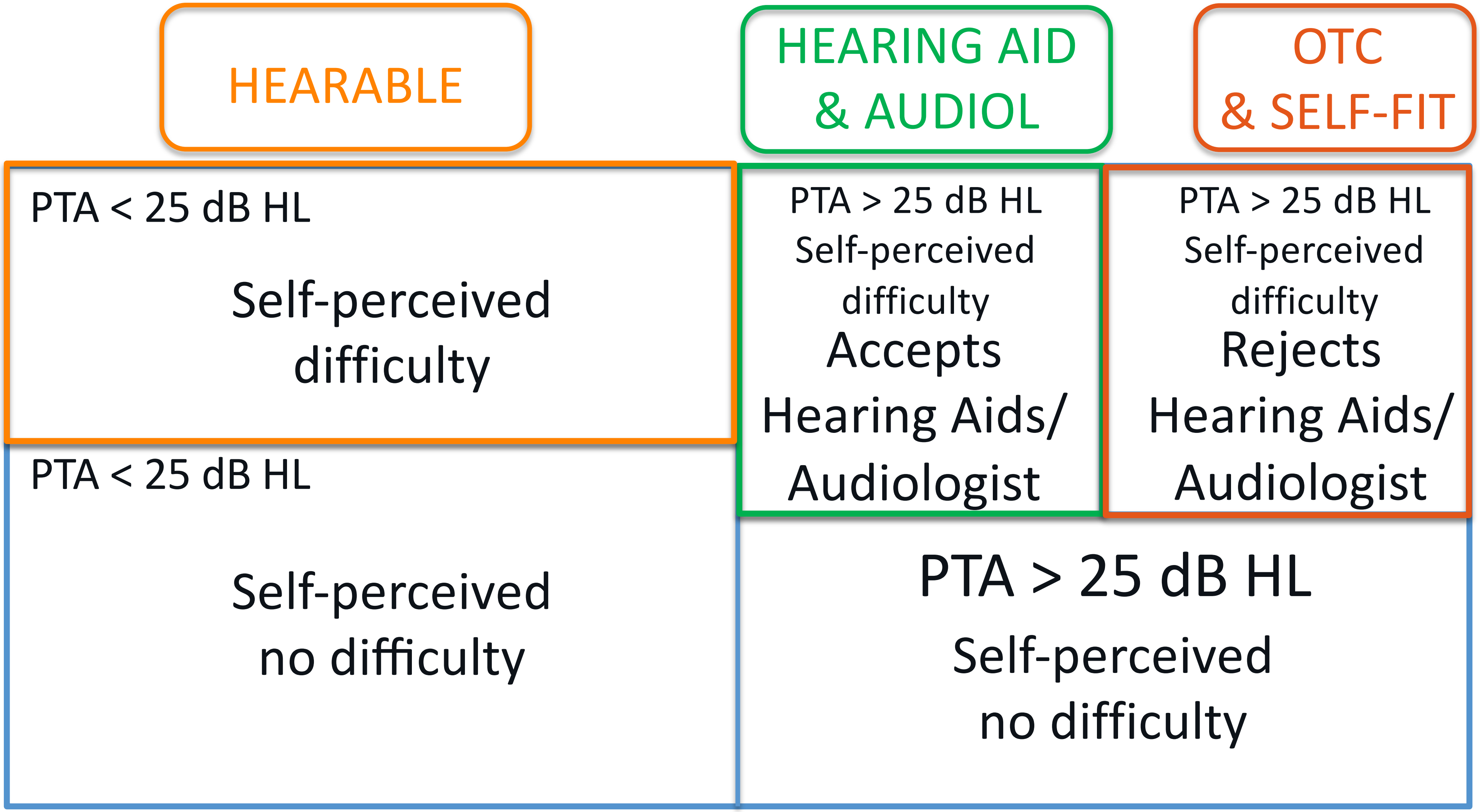


Technology for Speech in Noise Difficulty

Hearing Difficulty and Hearing Aid Use by Age Group




HEARABLE
HEARING AID & AUDIOL
OTC & SELF-FIT
PTA < 25 dB HL
Self-perceived difficulty
PTA > 25 dB HL
Self-perceived difficulty
Accepts Hearing Aids/ Audiologist
PTA > 25 dB HL
Self-perceived difficulty
Rejects Hearing Aids/ Audiologist
PTA < 25 dB HL
Self-perceived no difficulty
PTA > 25 dB HL
Self-perceived no difficulty

HEARABLE

PTA < 25 dB HL

26M

Self-perceived difficulty

PTA > 25 dB HL

Self-perceived difficulty

Accepts Hearing Aids/ Audiologist

PTA > 25 dB HL

Self-perceived difficulty

Rejects Hearing Aids/ Audiologist

PTA < 25 dB HL

Self-perceived no difficulty

PTA > 25 dB HL

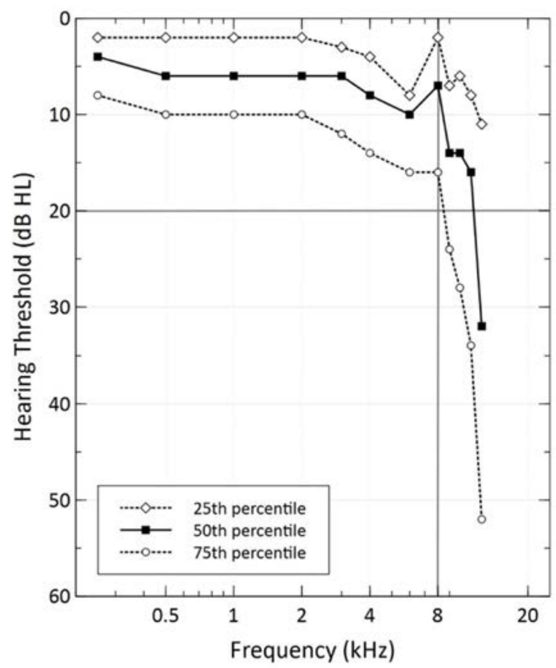
Self-perceived no difficulty

Objective

- Which factors are indicators of a poor ability to understand speech in noise?

Participants

- ✓ N = 122, normal or ‘near-normal’ hearing
- ✓ Normal tympanometry
- ✓ 30 – 55 years of age
- ✓ History of noise exposure and/or musical experience

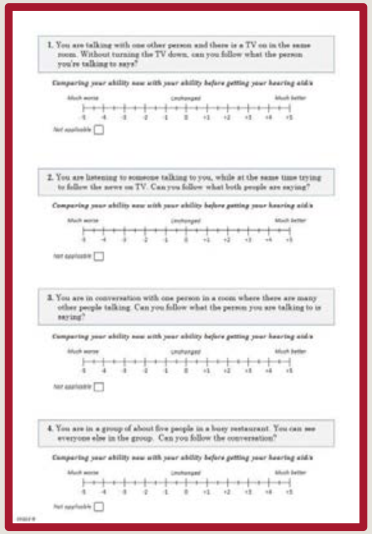


Yeend *et al.*, 2017

STUDY DESIGN

Behavioural	Electro-physiology	Hearing Experiences
• 122 participants • Online survey • Audiometry • Auditory processing • Cognitive skills	• 68 participants • Five tests [CAEP’s, IRN, speech ABR, click ABR, EFR] • Designed to support behavioural measures	• 50 participants • Interviews & online survey • Exploring listening difficulties, impacts and strategies

Composite Speech-in-Noise Score



1. You are talking with one other person and there is a TV on in the same room. Without turning the TV down, can you follow what the person you're talking to says?

Comparing your ability now with your ability before getting your hearing aid/s

Much worse — Unchanged — Much better

-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5

Not applicable ☐

2. You are listening to someone talking to you, while at the same time trying to follow the news on TV. Can you follow what both people are saying?

Comparing your ability now with your ability before getting your hearing aid/s

Much worse — Unchanged — Much better

-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5

Not applicable ☐

3. You are in conversation with one person in a room where there are many other people talking. Can you follow what the person you are talking to is saying?

Comparing your ability now with your ability before getting your hearing aid/s

Much worse — Unchanged — Much better

-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5

Not applicable ☐

4. You are in a group of about five people in a busy restaurant. You can see everyone else in the group. Can you follow the conversation?

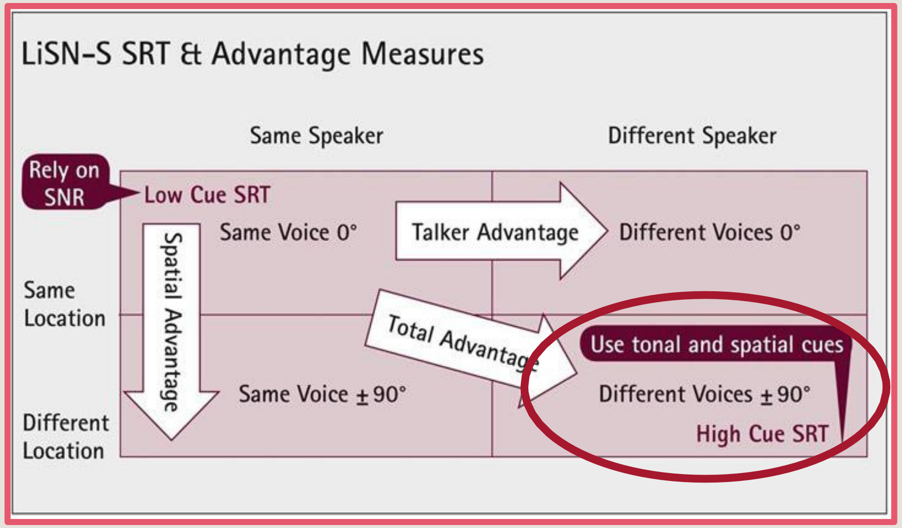
Comparing your ability now with your ability before getting your hearing aid/s

Much worse — Unchanged — Much better

-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5

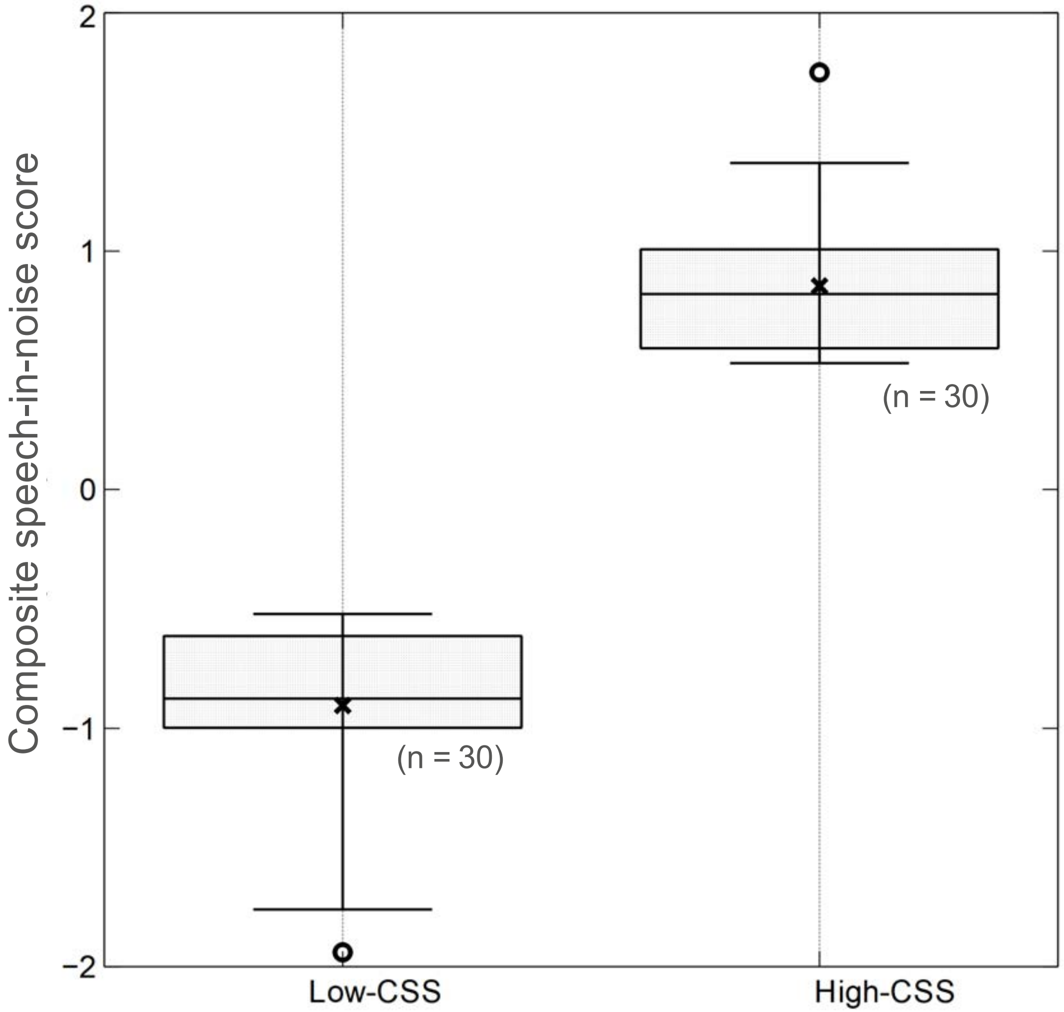
Not applicable ☐

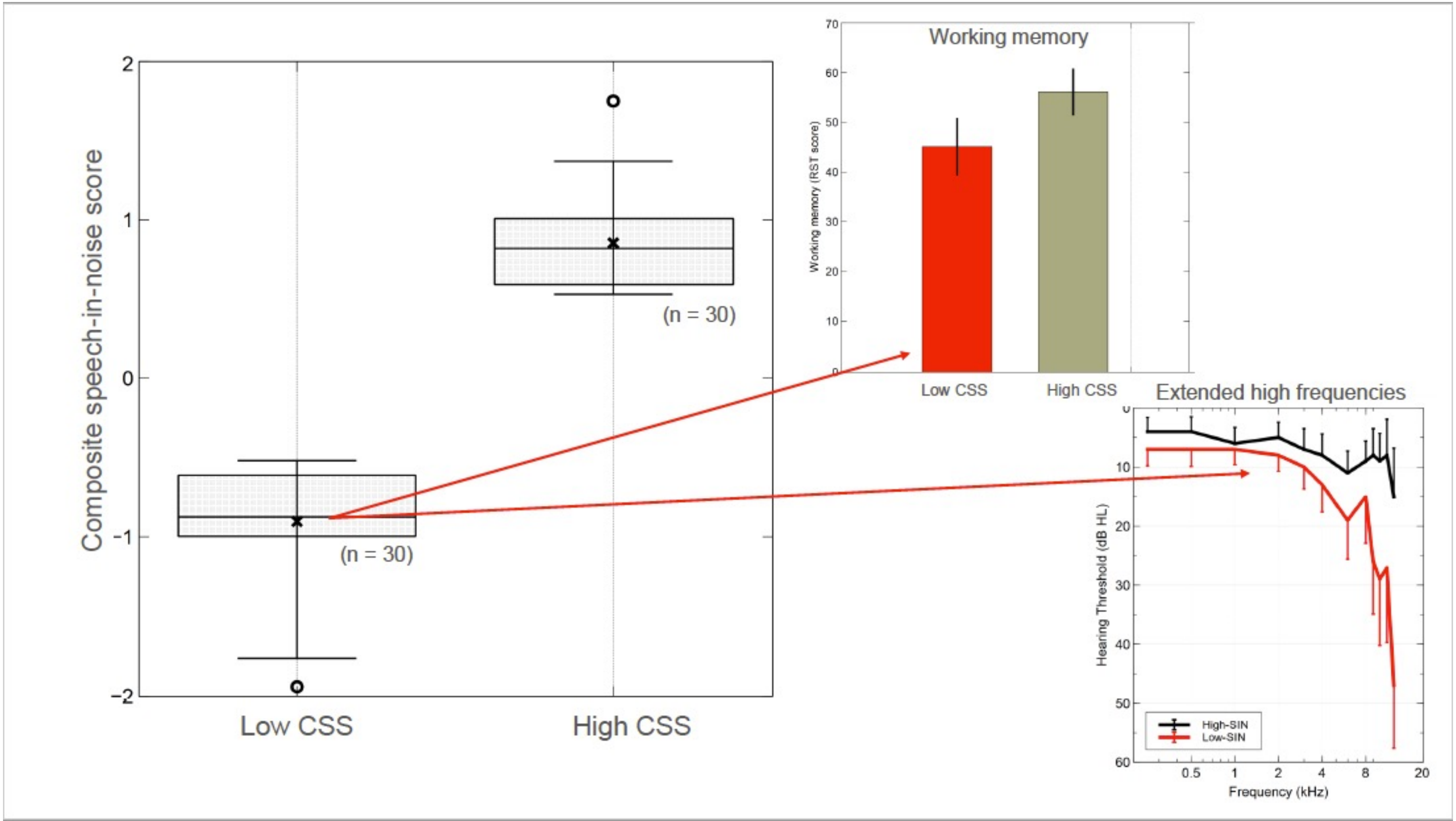
SSQ12 speech items



LiSN-S

NAL-DCT

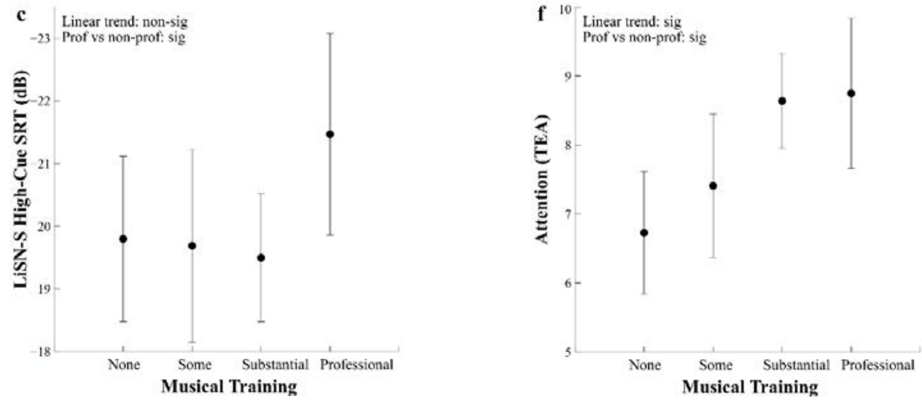

Composite speech-in-noise score
2
1
0
−1
−2
(n = 30)
(n = 30)
Low-CSS
High-CSS


Composite speech-in-noise score
2
1
0
-1
-2
(n = 30)
(n = 30)
Low CSS
High CSS
Working memory
Working memory (RST score)
70
60
50
40
30
20
10
0
Low CSS
High CSS
Extended high frequencies
Hearing Threshold (dB HL)
0
10
20
30
40
50
60
0.5
1
2
4
8
20
Frequency (kHz)
High-SIN
Low-SIN

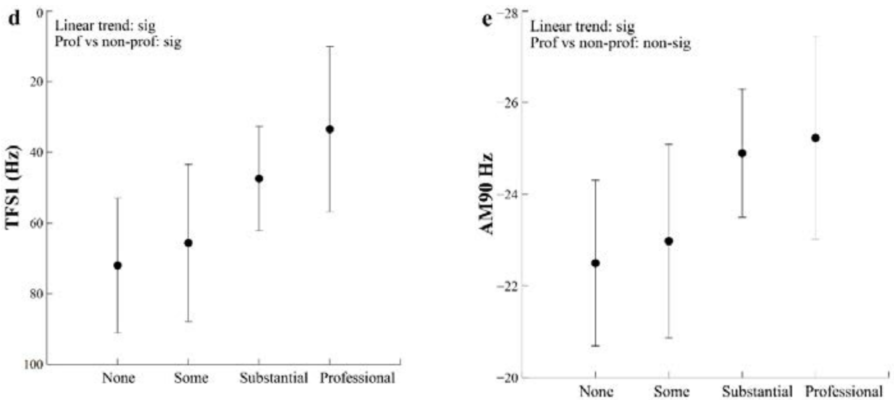
Musical experience and training

1) Does musical training benefit speech-in-noise perception, temporal processing and cognition?

Musical training and experience	(n)
None	30
Some *(< 8 years)*	22
Substantial *(≥ 8 years including formal exams)*	50
Professional *(working as musician)*	20

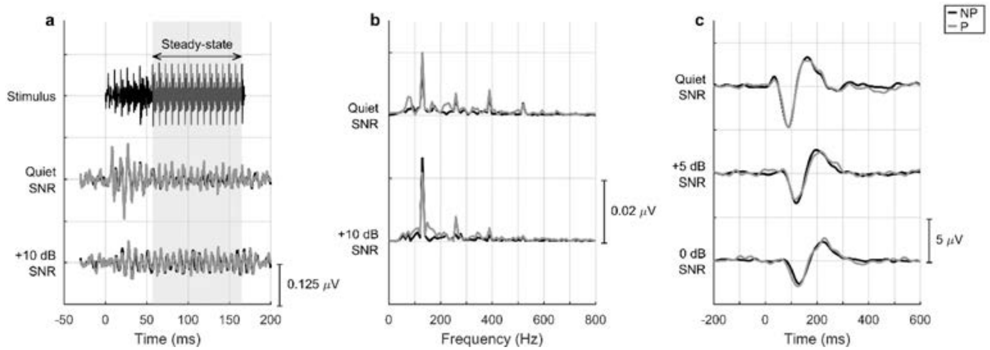


BEHAVIOURAL



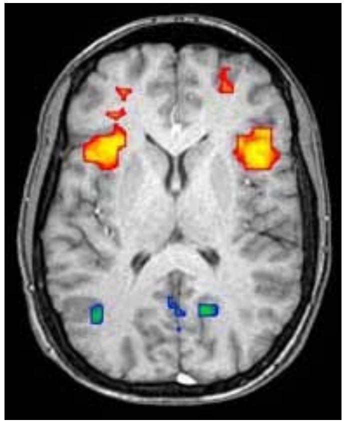
ELECTROPHYSIOLOGY

2) Does the musician advantage have a neurophysiological basis?



Superior attentional skills appear to be a key factor underlying the musician advantage for understanding speech in noise.

Cognitive Integration with Technology



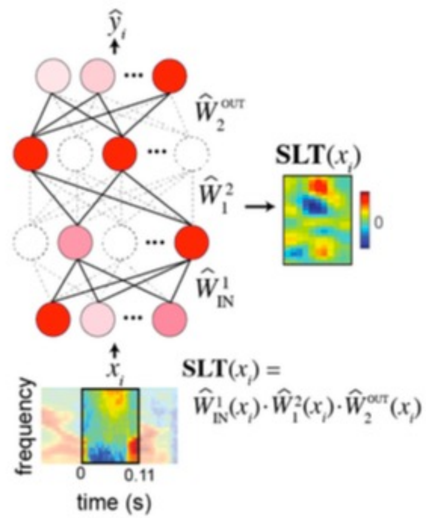
- Use cognitive measures in the clinic:
  - Predict difficulty with speech in noise
- Neurophysiological sensors embedded in hearing aids
  - Measure listening effort, focus

Separating Speech with Machine Learning

Two Talkers

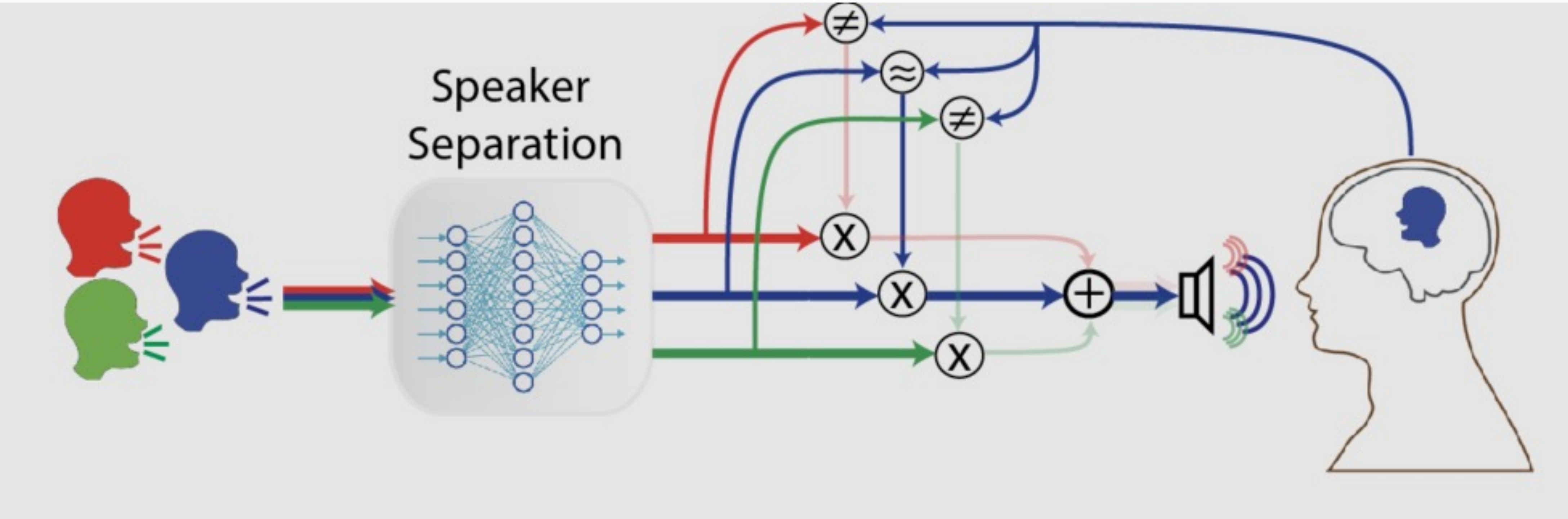
Talker One

Talker Two

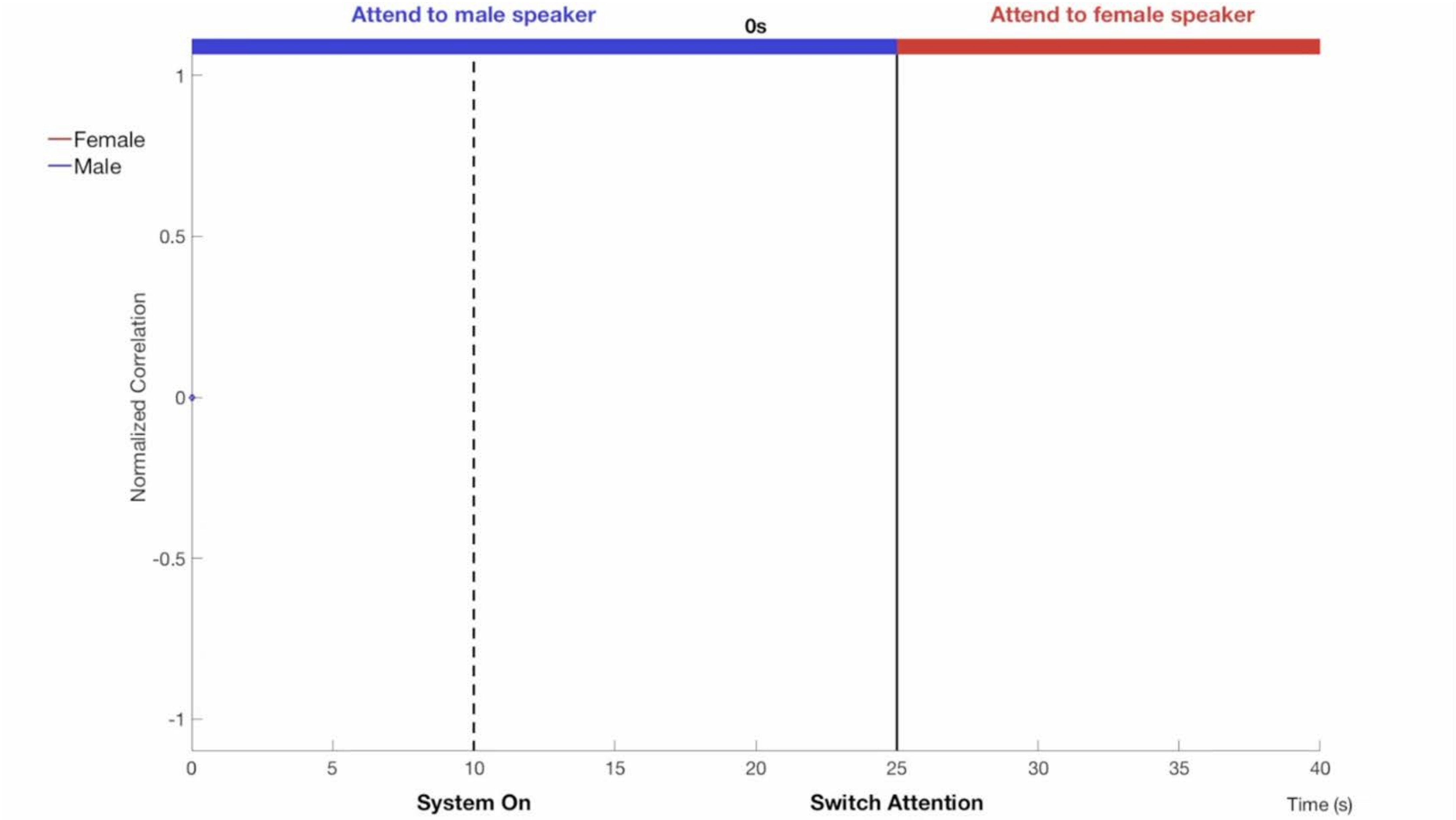


Mesgarani et al., 2017

Brain Controlled Hearing Aid



Mesgarani et al., 2018

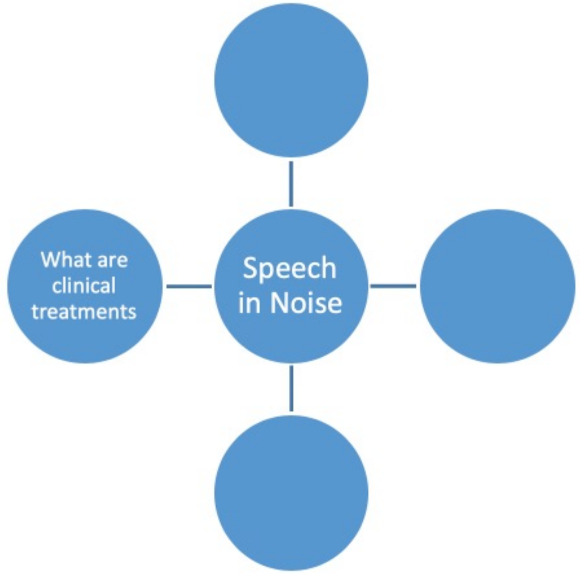


Attend to male speaker
0s
Attend to female speaker
1
0.5
0
-0.5
-1
Female
Male
Normalized Correlation
0
5
10
15
20
25
30
35
40
System On
Switch Attention
Time (s)

What Patient Complaints Can Hearing Aid Technology Address?

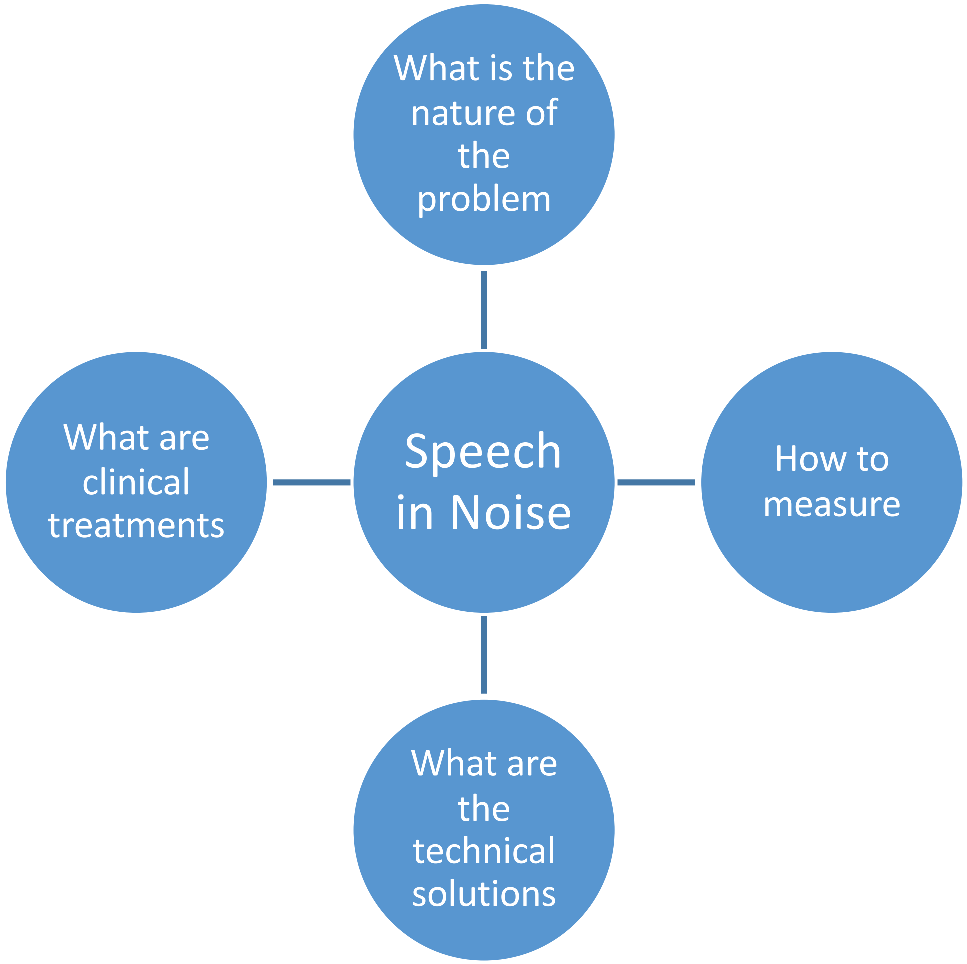
- Understanding
- Comfort
- Effort
- Fatigue
- Social interaction
- Conversation following
- Attention and focus

Clinical Implications



Implications for Clinical Treatment

- Understand client needs
  - Is it speech understanding or noise tolerance?
  - Are they predisposed for poorer speech-in-noise performance?
    - Adjust treatment, counseling accordingly
- Counsel on multifaceted aspects of poor speech in noise ability
- Measure meaningful outcomes
  - Not live voice word lists
- For normal audiograms with speech complaints
  - Measures 12 kHz, working memory
  - Provide non-traditional solutions
    - Hearables
    - Attention training


What is the nature of the the problem
What are clinical treatments
Speech in Noise
How to measure
What are the technical solutions

Thank you!

Brent.edwards@nal.gov.au

@bwedwards