Current trends in *hidden* hearing loss

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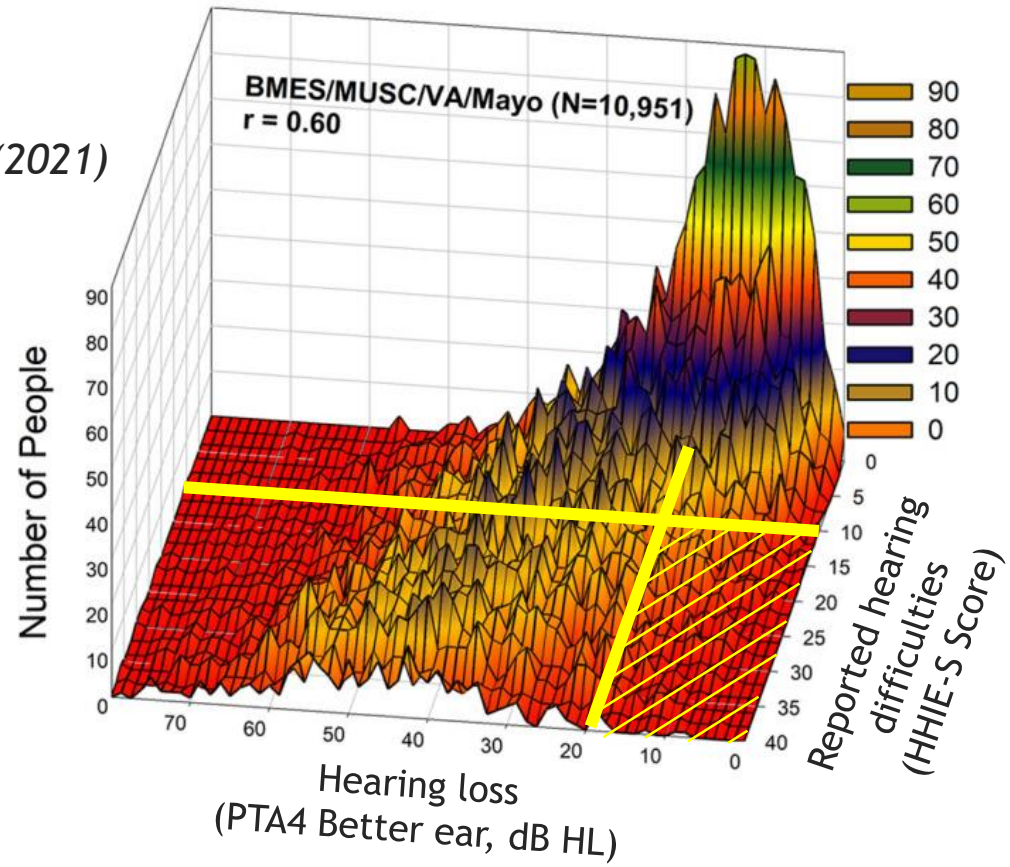
19th September 2022, Master of Clinical Audiology, Macquarie University

The cocktail-party problem

Humes (2021)



Structure

Part 1 – [*NAL Study 1*] Problem statement

Part 2 – Underlying mechanisms (animal models)

Part 3 – Diagnostic of hidden hearing loss
- ✓ Existing biomarkers
- ✓ Forthcoming research

Part 4 – Clinical management of HHL hearing difficulties
- ✓ Therapeutics interventions
- ✓ [*NAL Study 2*] Low-gain hearing aids
- ✓ [*NAL Study 3*] AirPods Pro hearables

Part 1 – [NAL Study 1] Problem statement

AJA

Research Article

Discovering the Unmet Needs of People With Difficulties Understanding Speech in Noise and a Normal or Near-Normal Audiogram

Kiri Mealings,[a] Ingrid Yeend,[a] Joaquin T. Valderrama,[a,b] Megan Gilliver,[a] Jermy Pang,[a] Jason Heeris,[a] and Pamela Jackson[a]


Kiri Mealings


Ingrid Yeend


Joaquin Valderrama


Megan Gilliver


Jermy Pang


Jason Heeris


Pamela Jackson

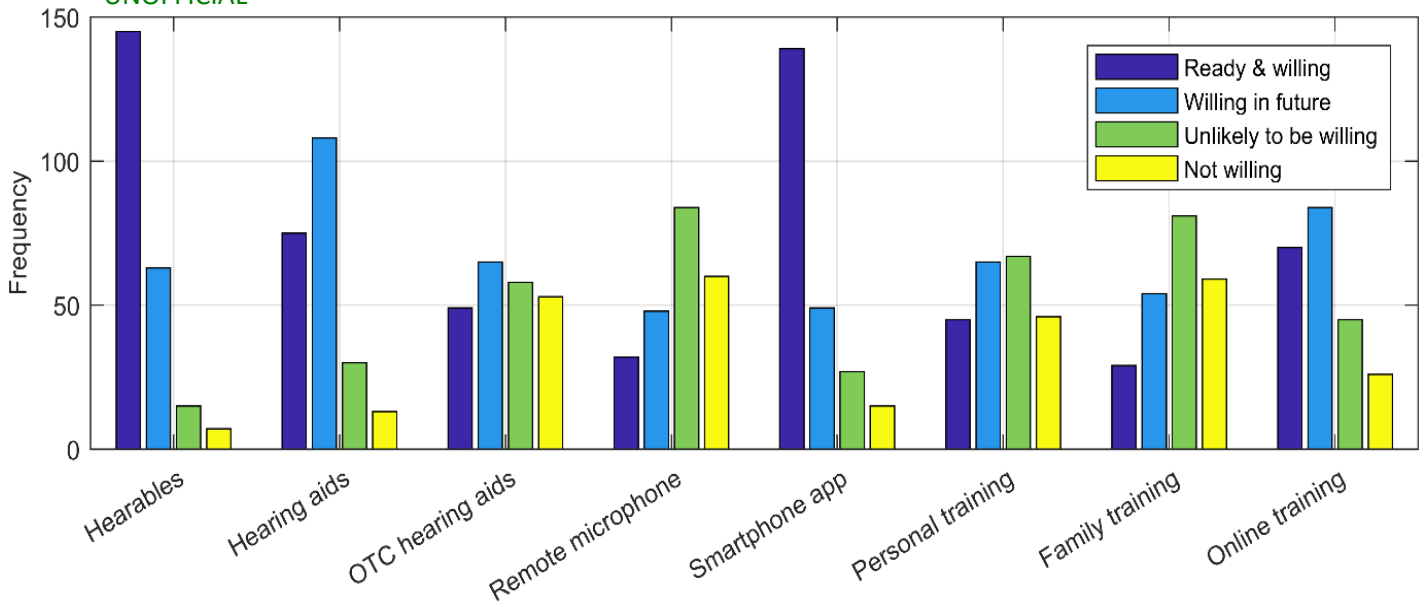
We used *design thinking* strategies to **identify the unmet needs** of people with speech-in-noise hearing difficulties (NH-MHL) and the clinicians who treat them

Methods

- ✓ Questionnaires from 233 NH-MHL and 49 clinicians
- ✓ Personal interviews from 21 NH-MHL and 8 clinicians

Relevant findings

Hearing performance was not checked uniformly across participants. While most of them reported to have done an audiogram (94%), only 33% of them did a speech-in-quiet test, and 22% did a speech-in-noise tests.



Most participants were **willing to try** hearing aids and hearables

76% did not receive any type of treatment option from their audiologists

79% were not offered a follow-up appointment

72% of participants were **only 'partially satisfied' or 'not satisfied'** with the appointment. They complained that:

(1) they received very **limited help**, advice or treatment options;
(2) they found the **cost** of hearing aids prohibitive;
(3) the **testing was not sufficient** to describe their difficulty or seemed biased to the interpretation of the audiologist;
(4) the options provided **did not solve the problem** or would not help them long-term;
(5) they felt that the audiologist was pushing to **sell hearing aids**; and
(6) they were told they had good hearing but, still, they had issues with their hearing.

In their own words

About their hearing difficulties

*<<I think that **other people must be able to filter that background noise** and put it down to a lower level so that they can focus on conversation, so I must have a problem because I can't do that.>>*

Change of behaviour

*<<**It just makes me feel disinclined to go out**, and when I do go I tend to avoid restaurants and cafes and anything which is likely to be a crowd of people, unfortunately.>>*

Frustration and anxiety for potential misinterpretation

*<<**I think that people feel I am rude** because sometimes you nod and smile at the wrong point because you're not following what's happening.>>*

Impact on their quality of life

*<<**I have to try harder to hear**. I can't always hear what they're speaking to me about, or questions. It takes a lot of concentration>>*

What they would love to have

*<<Something **easy, attractive and unobtrusive** which **enhances my hearing**.>>*

Unmet needs

Need 1. A way to **improve the communication experience** in groups of people with substantial background noise.

Need 2. A way to improve and standardize **assessment protocols** to enable the provision of rehabilitation procedures and options tailored to each individual.

Need 3. A way to **evaluate different treatment options** to provide clinicians with evidence-based information about their effectiveness.

Need 4. A way to understand the population's insights about the **acceptability of technological solutions** to provide industry with guidelines for creating less stigmatized and more comfortable solutions.

Part 2 – Underlying mechanisms

Part 1 - Problem statement

Part 2 - Underlying mechanisms (animal models)

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Part 4 - Clinical management
- ✓ Therapeutics interventions
- ✓ Low-gain hearing aids
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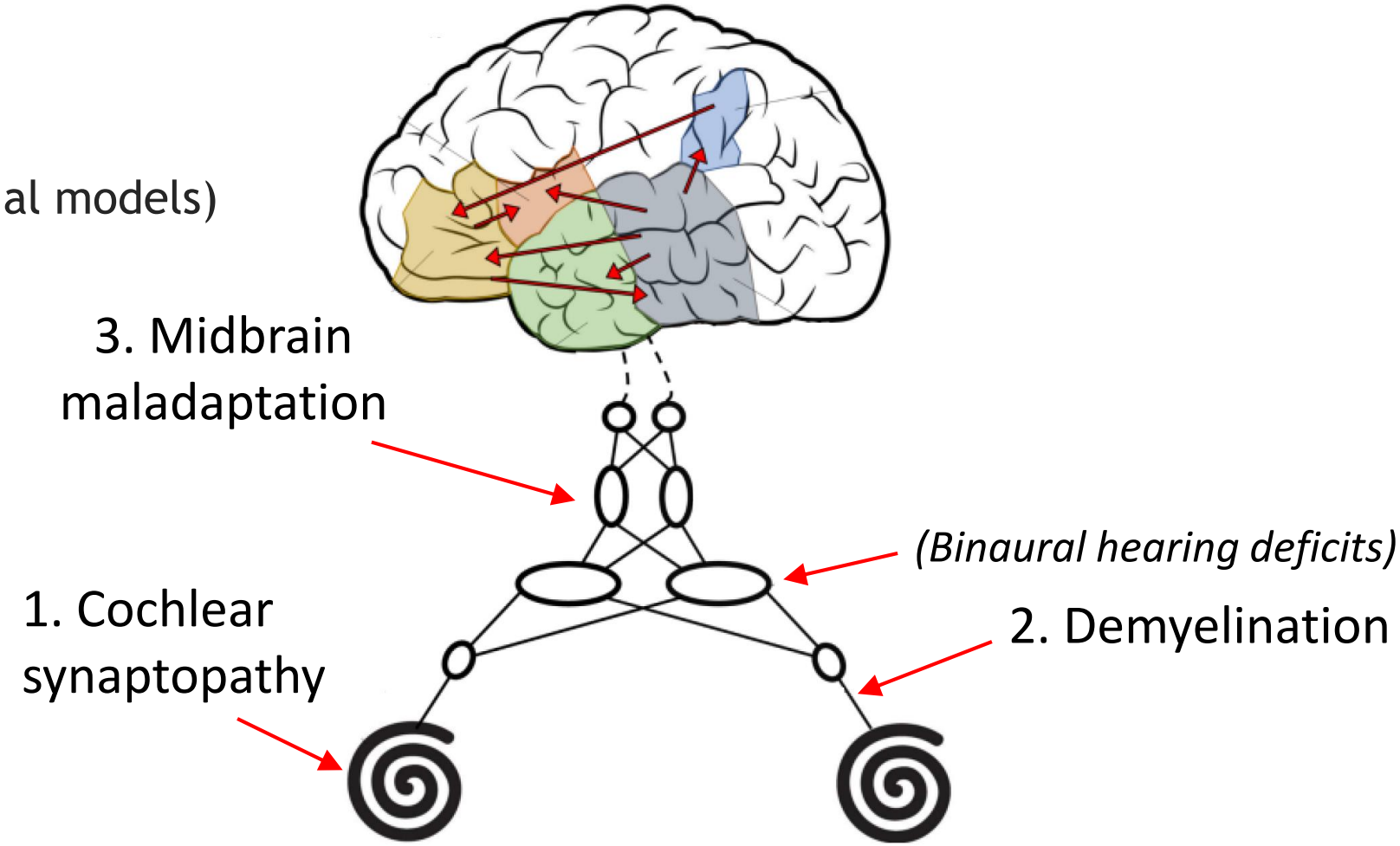
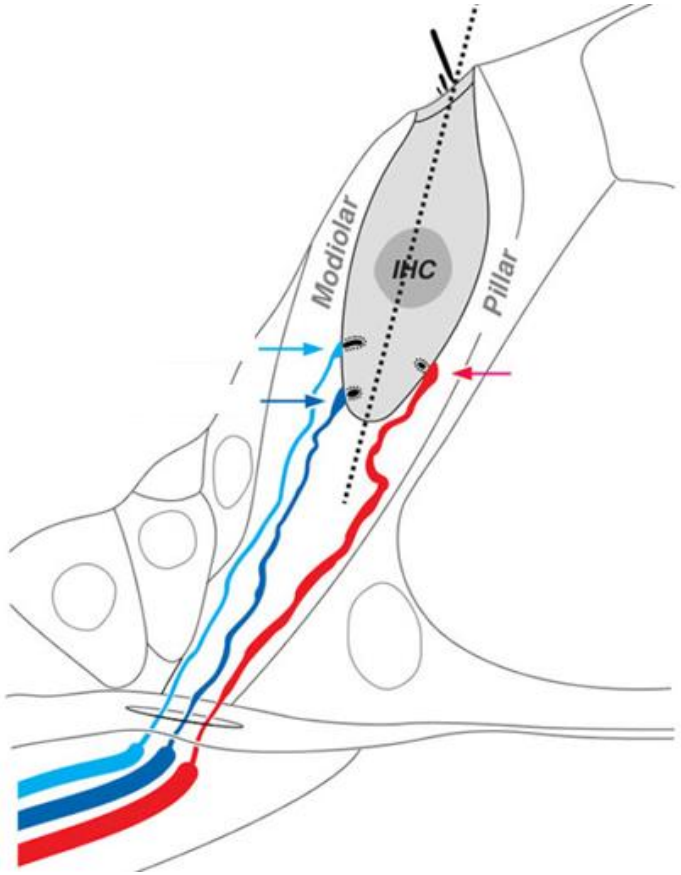
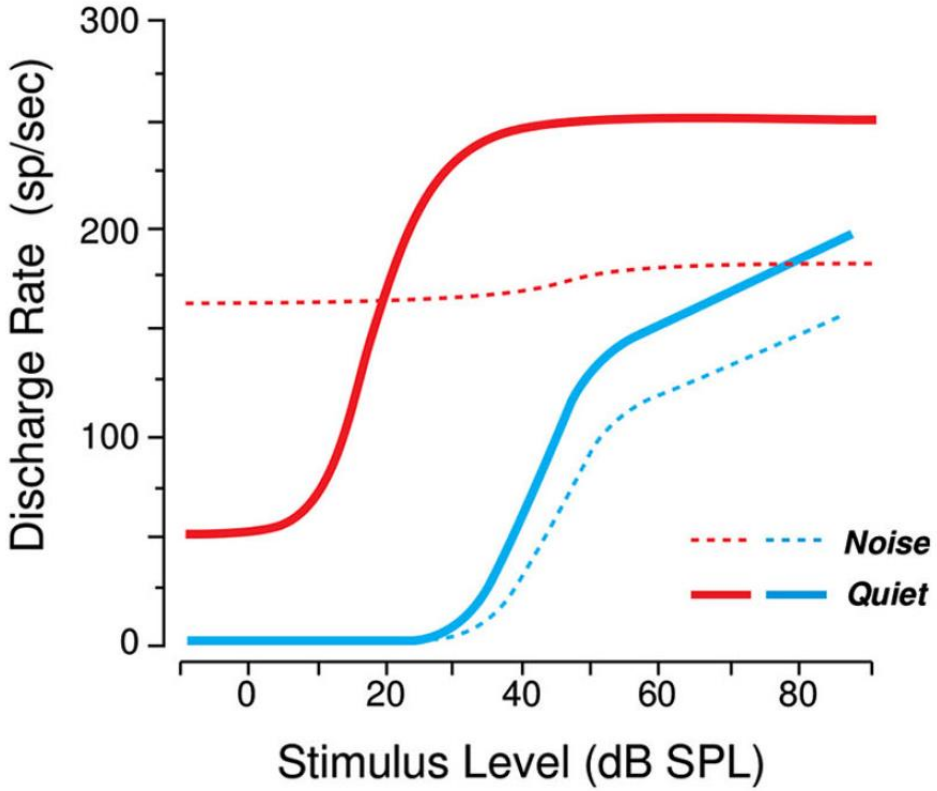


Pathology 1 – Cochlear synaptopathy

- 120 dB → I_{max} = 1,000,000,000,000 · I_{min}





HT fibres (LSRs) play an important role in speech perception in noise

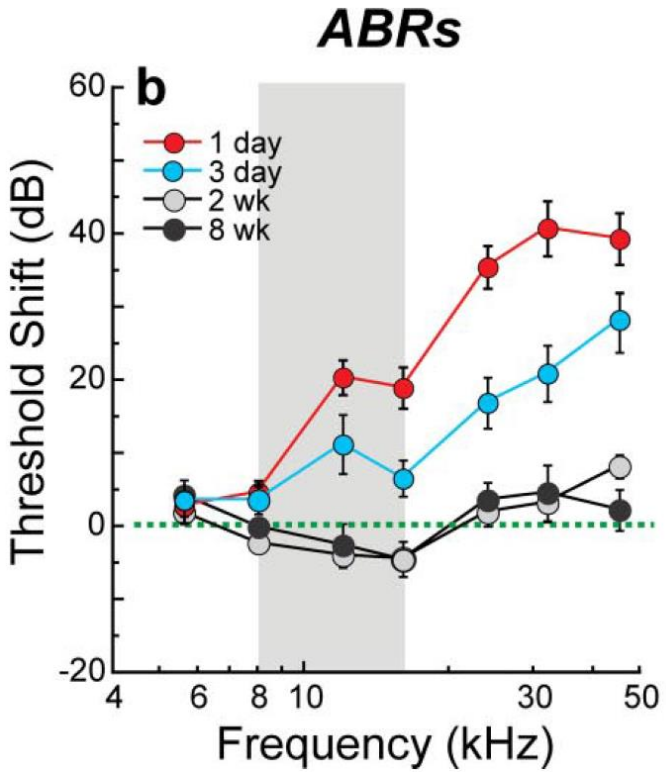
Behavioral/Systems/Cognitive

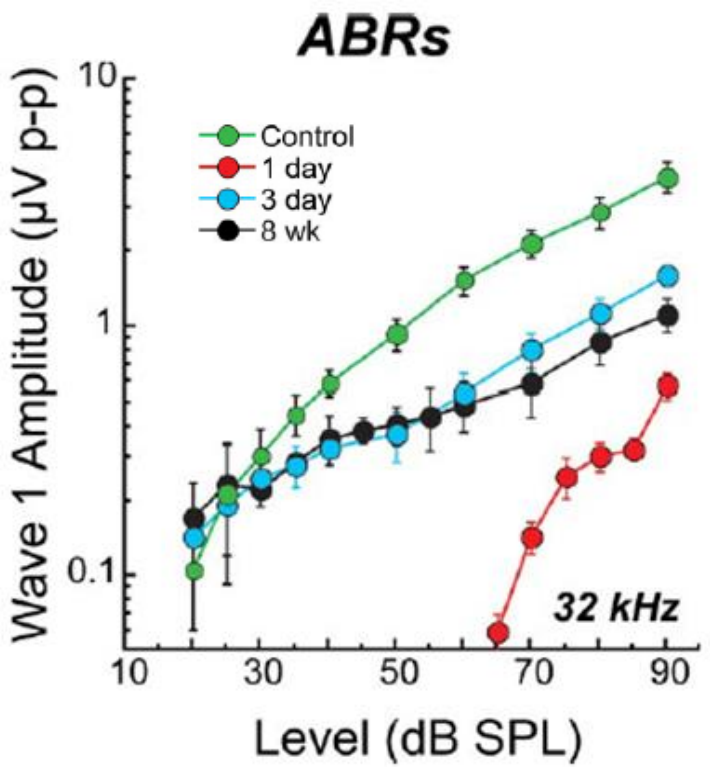
The Journal of Neuroscience, November 11, 2009 • 29(45):14077–14085 • 14077

Adding Insult to Injury: Cochlear Nerve Degeneration after "Temporary" Noise-Induced Hearing Loss

Sharon G. Kujawa[1,2,3,4] and M. Charles Liberman[1,2,4]

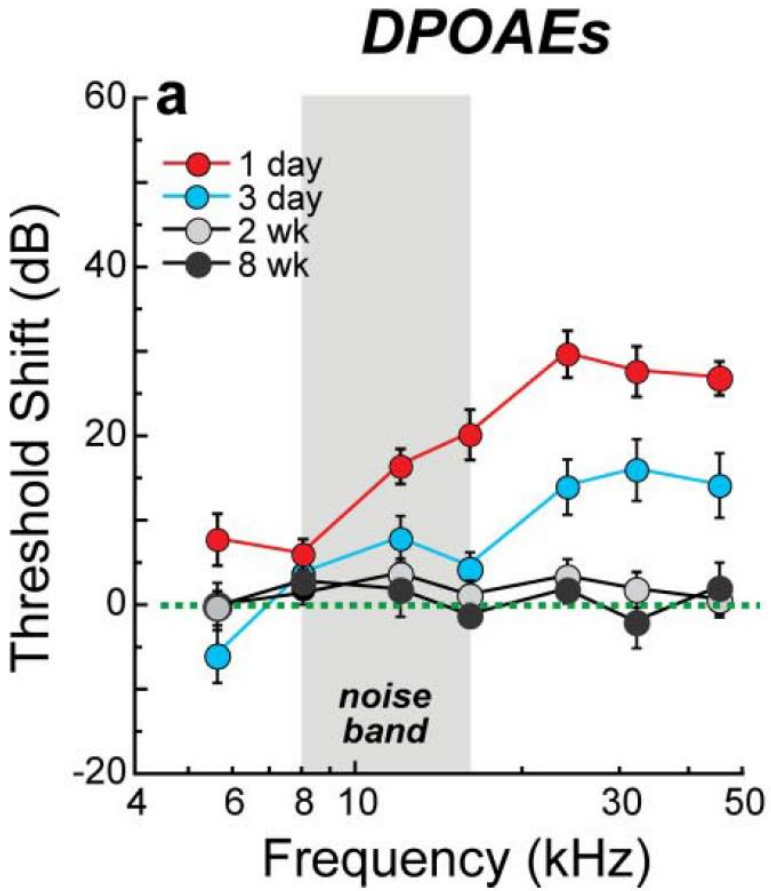
- Anaesthetized mice
- 8-16 kHz noise
- 2 h, 100 dB SPL

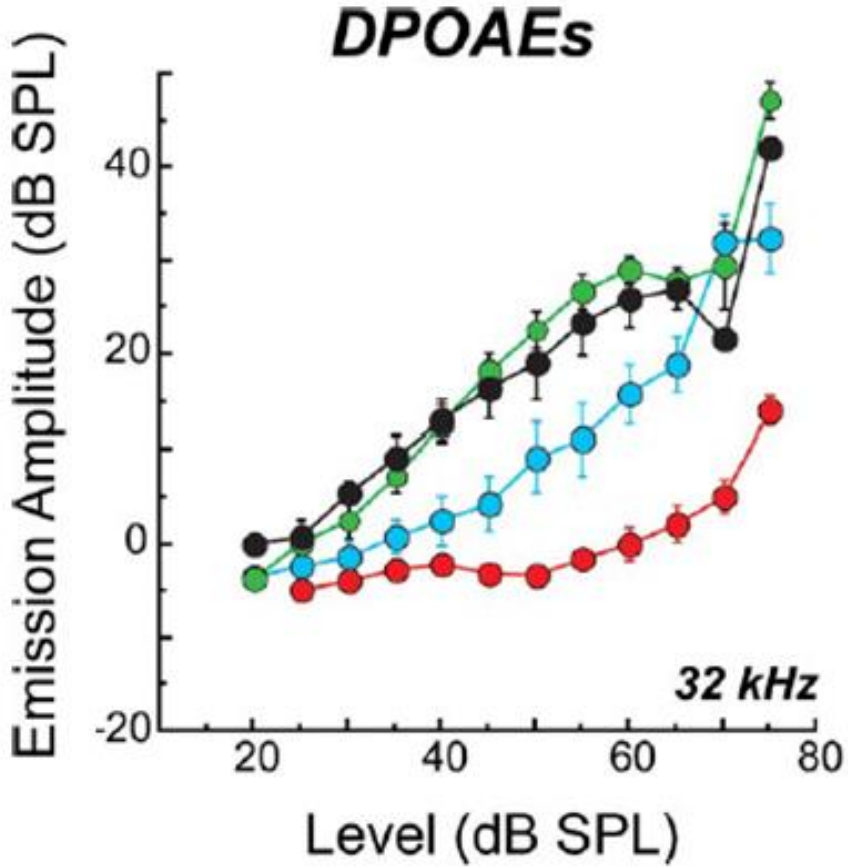




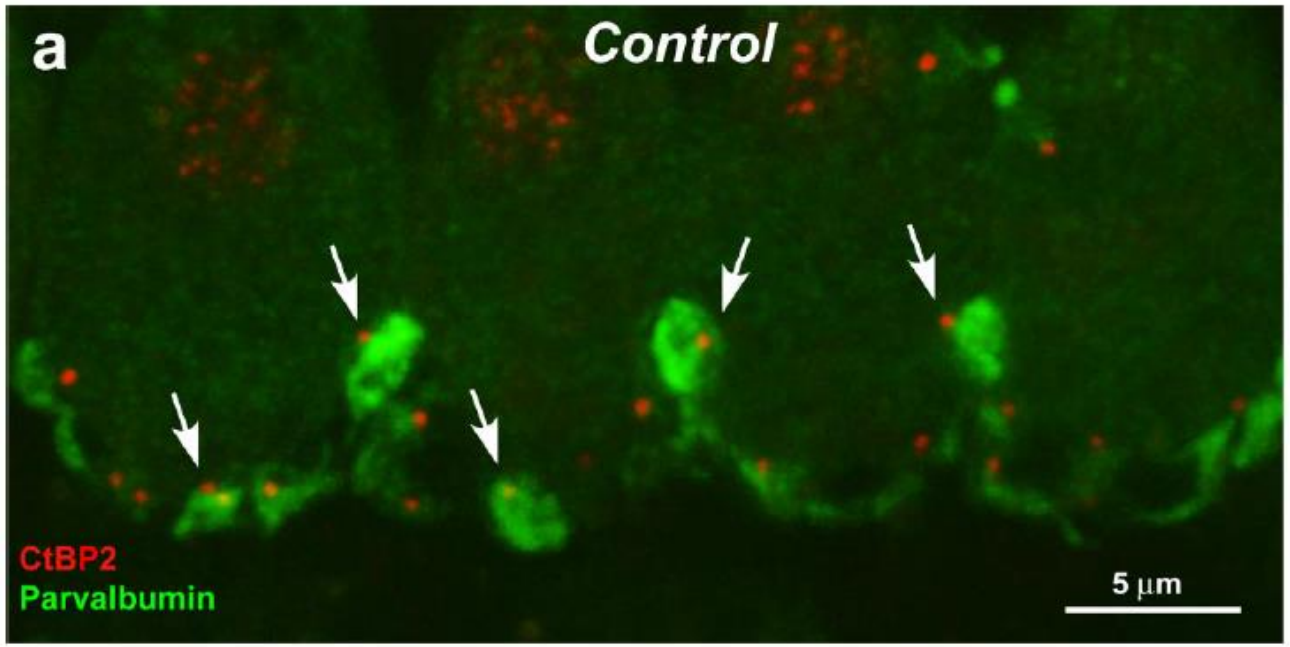
Noise damaged HT fibers

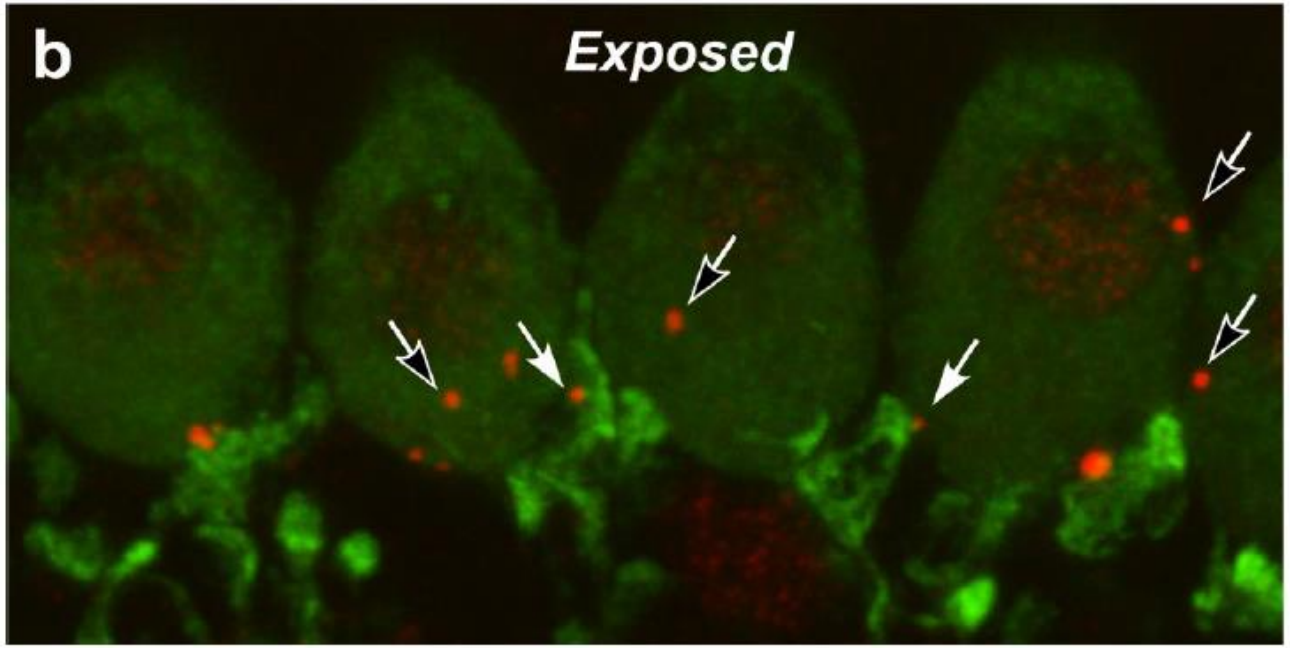
Were hair cells affected?

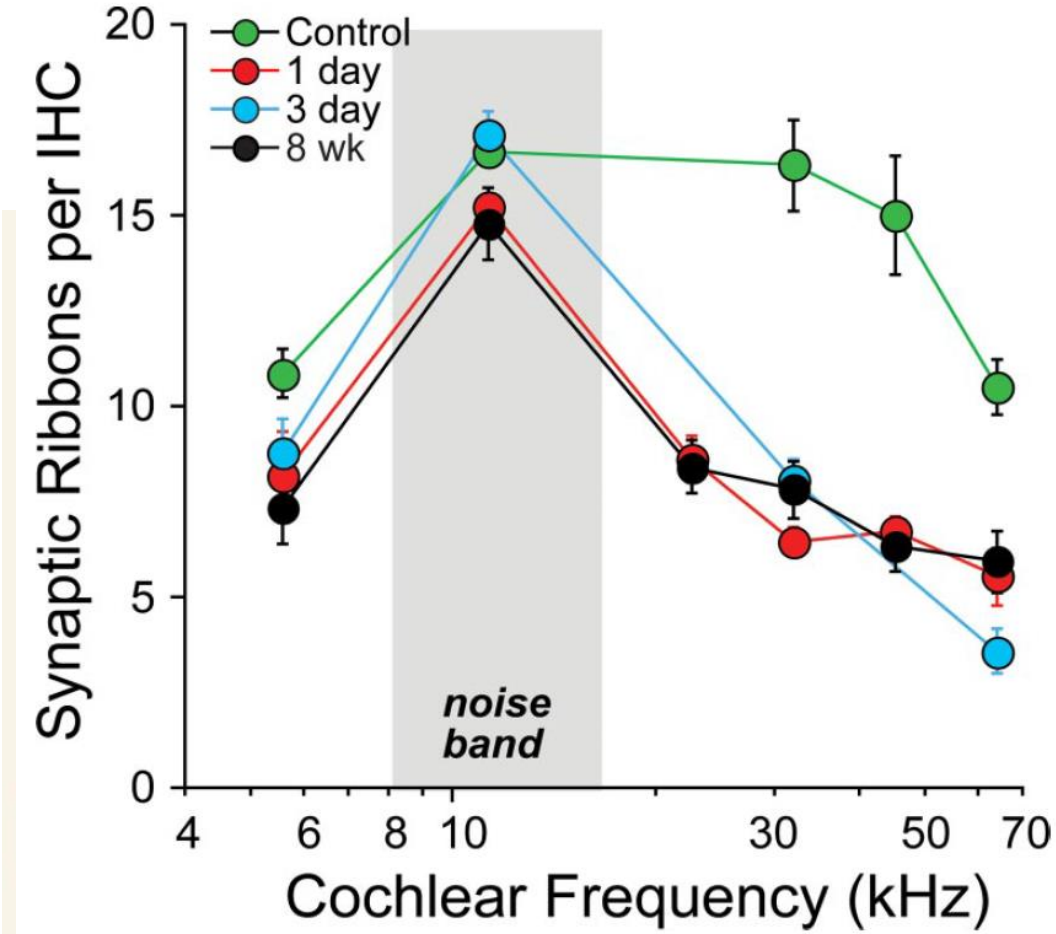




Noise exposure did not damage outer hair cells







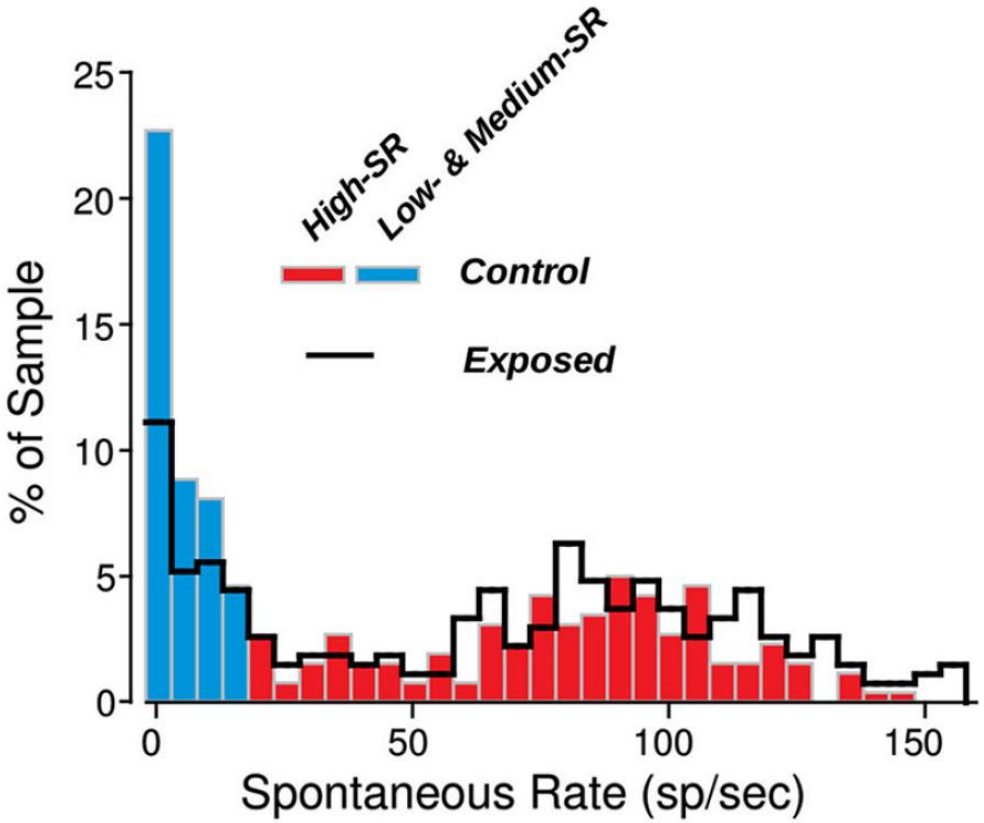
Noise-exposure “disconnects” hair cell synaptic ribbons from cochlear nerve terminals

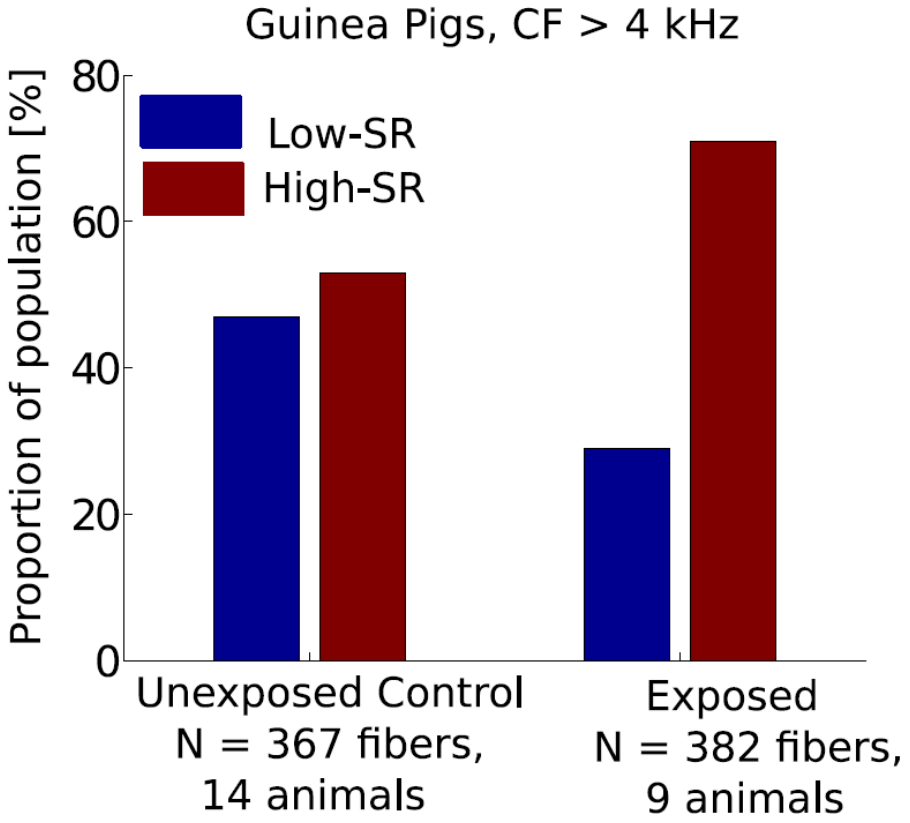
J Neurophysiol 110: 577–586, 2013.
First published April 17, 2013; doi:10.1152/jn.00164.2013.

Noise-induced cochlear neuropathy is selective for fibers with low spontaneous rates

Adam C. Furman,[2,4] Sharon G. Kujawa,[1,3,4] and M. Charles Liberman[1,2,4]

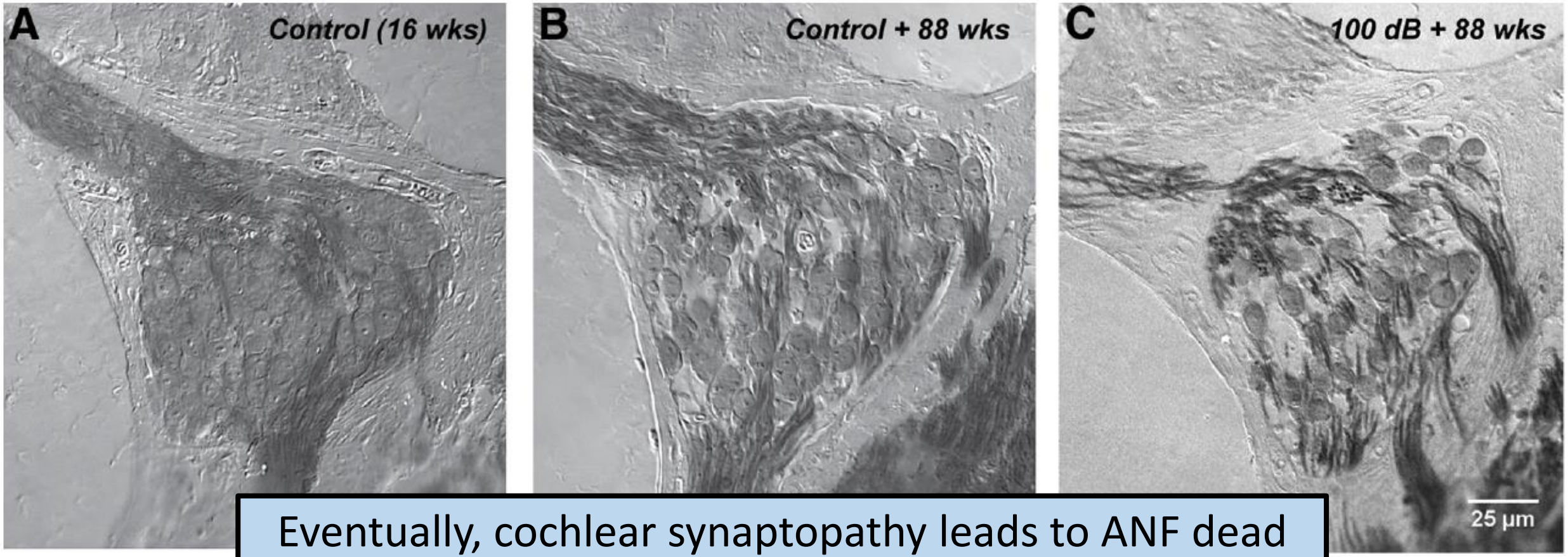
Noise exposure affects HT-ANF





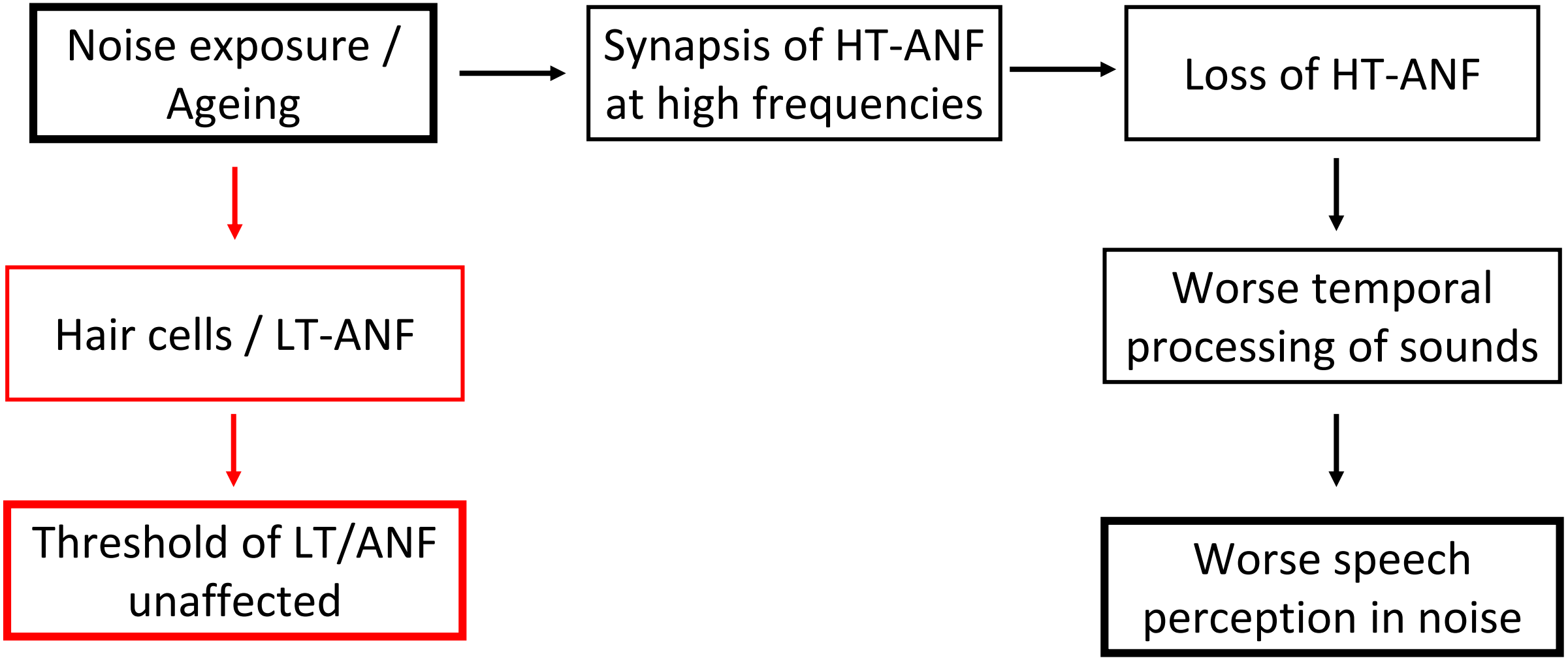
Aging after Noise Exposure: Acceleration of Cochlear Synaptopathy in "Recovered" Ears

Katharine A. Fernandez,[1,2] Penelope W.C. Jeffers,[2] Kumud Lall,[1,2] M. Charles Liberman,[1,2] and Sharon G. Kujawa[1,2,3]



Eventually, cochlear synaptopathy leads to ANF dead

Animal model cochlear synaptopathy



Quiz

- **What type of neurons participate mostly in understanding speech in noise?**
  - High-Threshold / Low-Spontaneous Rate Auditory Nerve Fibres
- **Who were the authors of a very relevant study that has influenced HHL research?**
  - Sharon Kujawa & Charles Liberman
- **In what year?**
  - 2009
- **According to this study, what happened to thresholds after noise exposure?**
  - They recovered
- **Does this mean that noise exposure is harmless?**
  - No, it affects HT-ANF
- **What is the consequence of losing HT-ANF?**
  - Worse temporal processing of sounds, thus worse speech perception in noise

Pathology 2 – Auditory nerve demyelination

nature COMMUNICATIONS

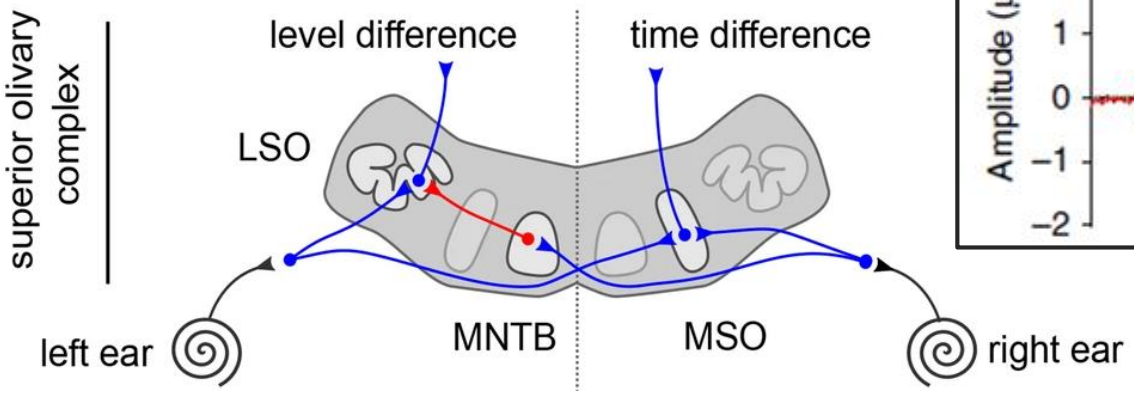
ARTICLE

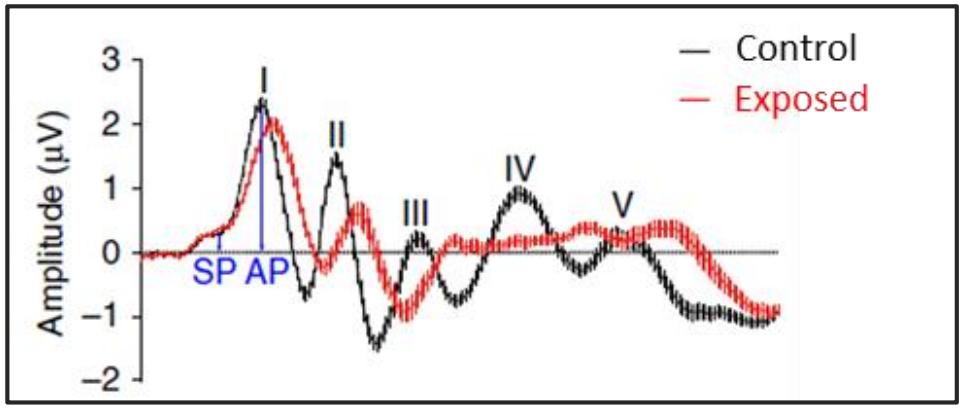
Received 23 Nov 2016 | Accepted 4 Jan 2017 | Published 17 Feb 2017

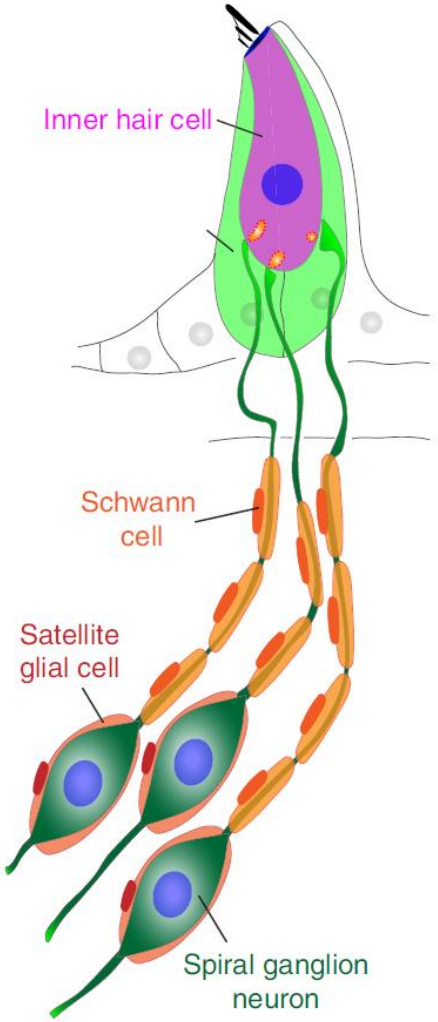
DOI: 10.1038/ncomms14487 OPEN

Transient auditory nerve demyelination as a new mechanism for hidden hearing loss

Guoqiang Wan[1,2] & Gabriel Corfas[1]







Pathology 3 – Midbrain maladaptation

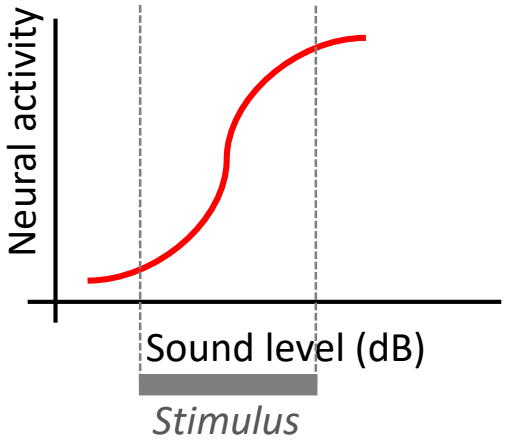
6430 • The Journal of Neuroscience, June 18, 2008 • 28(25):6430 – 6438

Behavioral/Systems/Cognitive

Rapid Neural Adaptation to Sound Level Statistics

Isabel Dean,[1] Ben L. Robinson,[1] Nicol S. Harper,[1,2] and David McAlpine[1]

[1]University College London Ear Institute and [2]CoMPLEX, University College London, London WC1X 8EE, United Kingdom



The neural activity **adapts** to the statistics of the stimulus to optimise the neural encoding of acoustic information

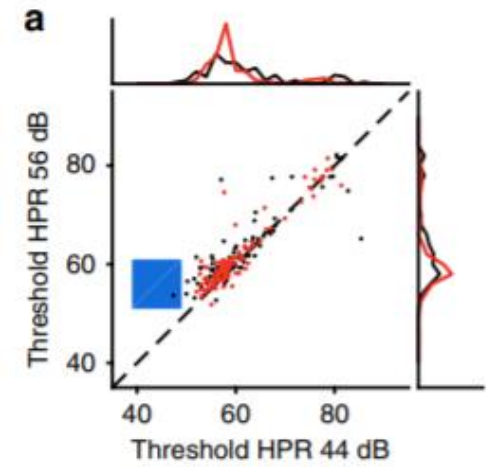
nature COMMUNICATIONS

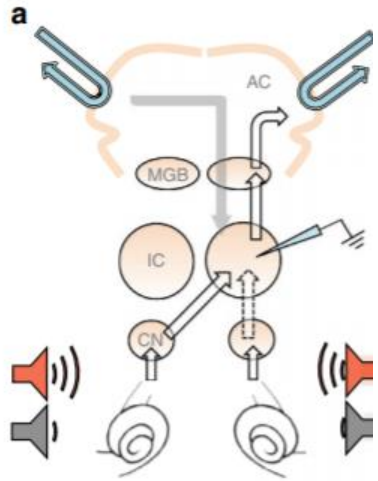
ARTICLE

DOI: 10.1038/s41467-018-06777-y OPEN

Hidden hearing loss selectively impairs neural adaptation to loud sound environments

Warren Michael Henry Bakay[1,2], Lucy Anne Anderson[1], Jose Alberto Garcia-Lazaro[1], David McAlpine[1,3] & Roland Schaette[1]





Noise exposure **impairs the neural adaptation** to loud sound environments

Part 3 – Diagnostic of HHL

Part 1 – Problem statement

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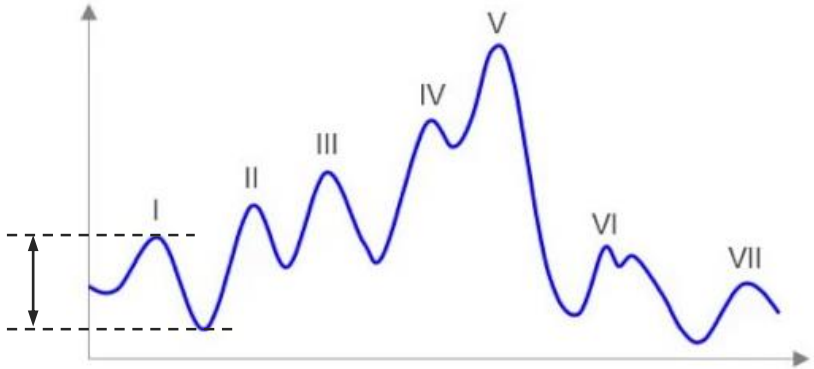
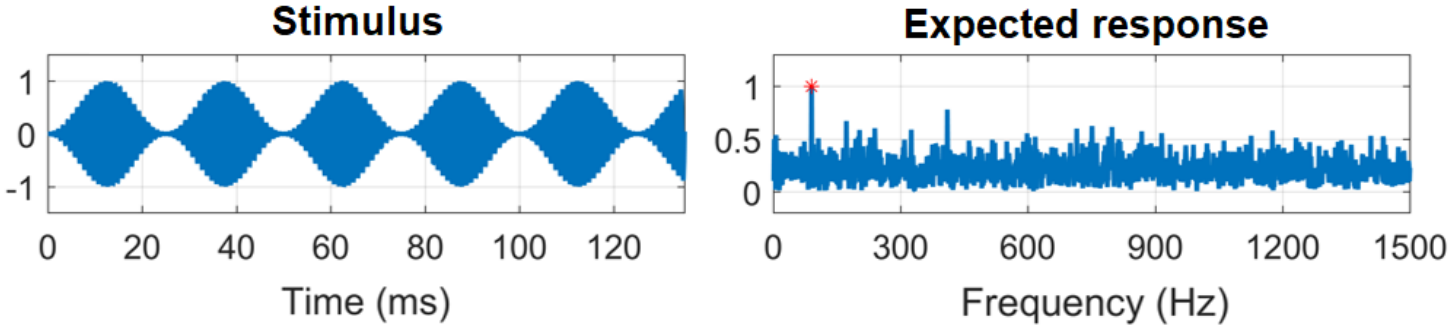
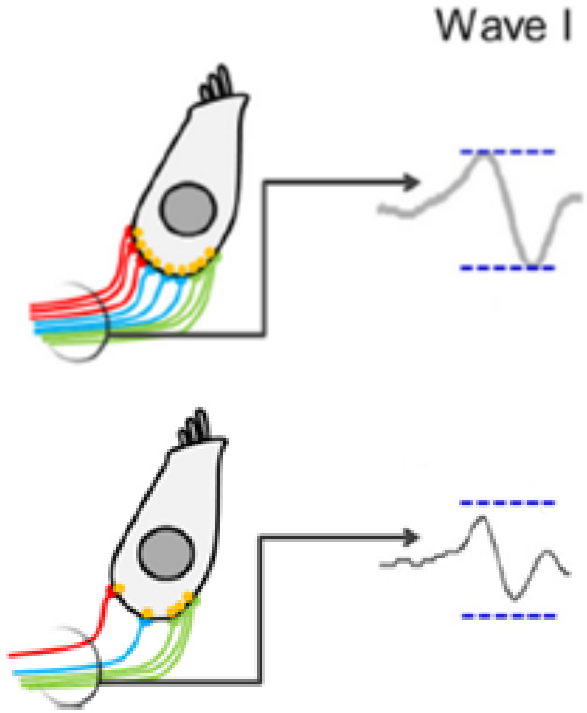
Biomarker 1. ABR wave I amplitude



Biomarker 2. Envelope Following Response (EFR)

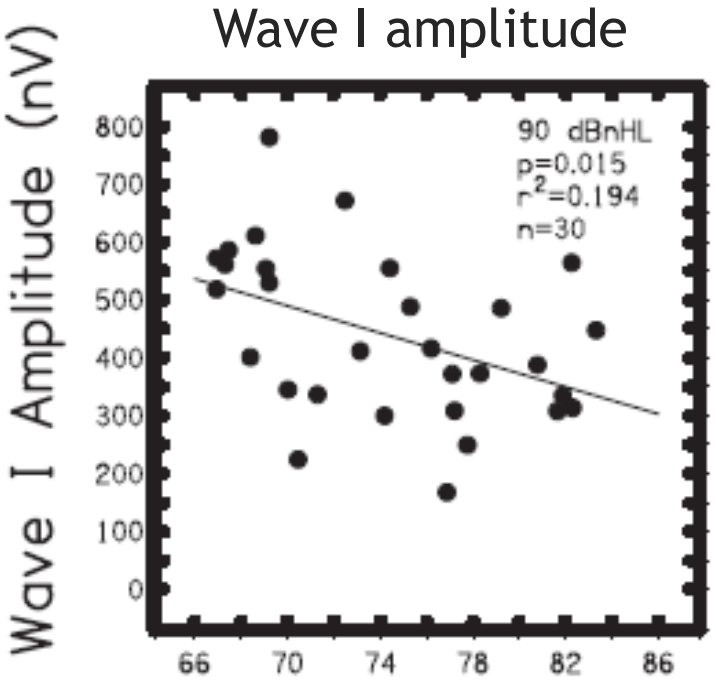


Biomarker 1 – ABR wave I amplitude

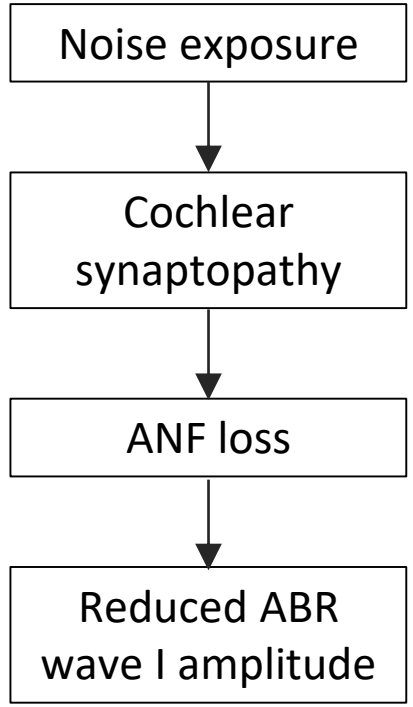


STAMPER AND JOHNSON / EAR & HEARING, VOL. 36, NO. 2, 172–184

Auditory Function in Normal-Hearing, Noise-Exposed Human Ears



Noise exposure background

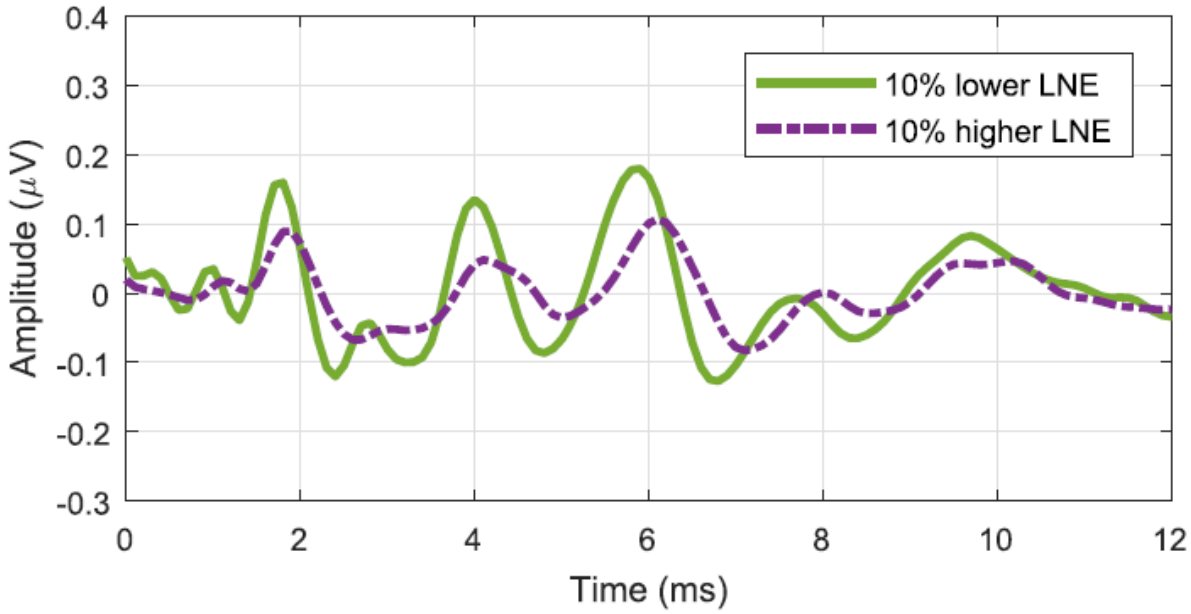


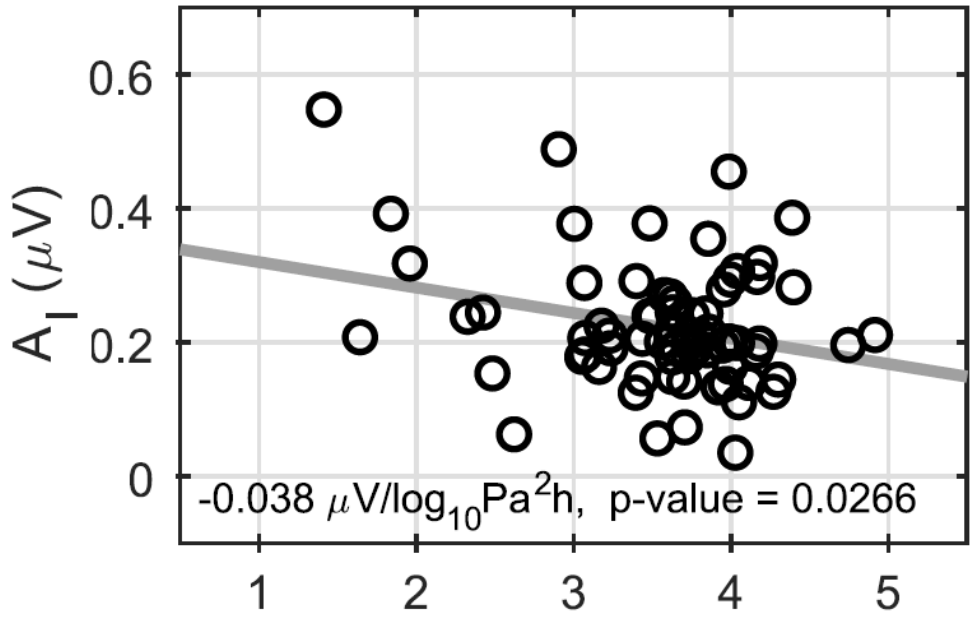
Research Paper

Hearing Research 365 (2018) 36–48

Effects of lifetime noise exposure on the middle-age human auditory brainstem response, tinnitus and speech-in-noise intelligibility

Joaquin T. Valderrama [a, b, c, *], Elizabeth Francis Beach [a, c], Ingrid Yeend [a, b, c], Mridula Sharma [b, c], Bram Van Dun [a, c], Harvey Dillon [a, c]

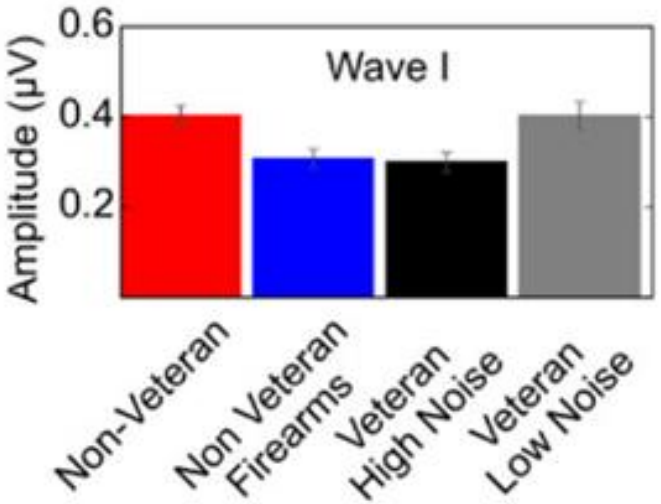




Noise exposure background

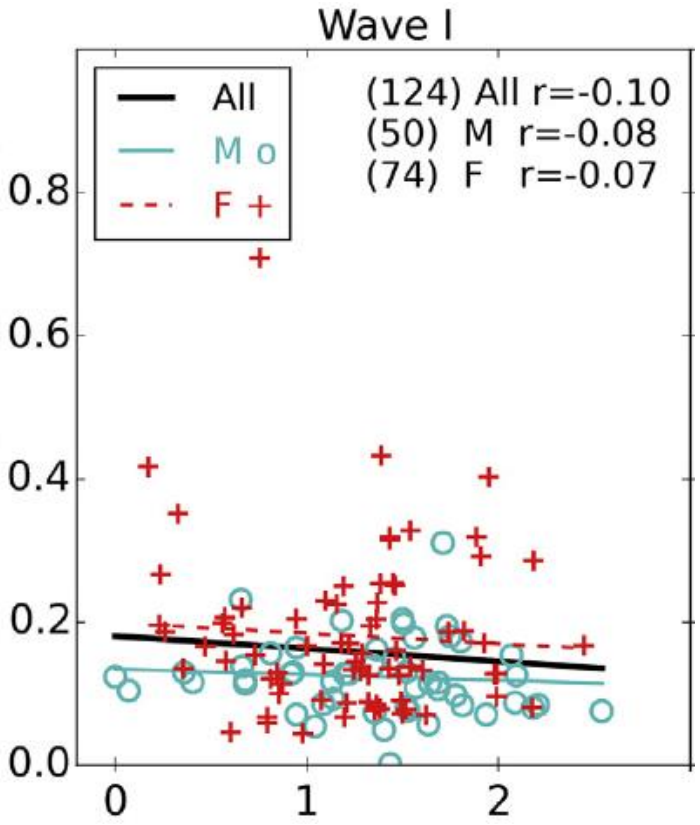
Auditory Brainstem Response Altered in Humans With Noise Exposure Despite Normal Outer Hair Cell Function

Naomi F. Bramhall[1], **Dawn Konrad-Martin**[1,2], **Garnett P. McMillan**[1], and **Susan E. Griest**[1,2]



RELEVANT FACTORS

- Humans vs animals
- Noise exposure estimates
- Inter-subject variability



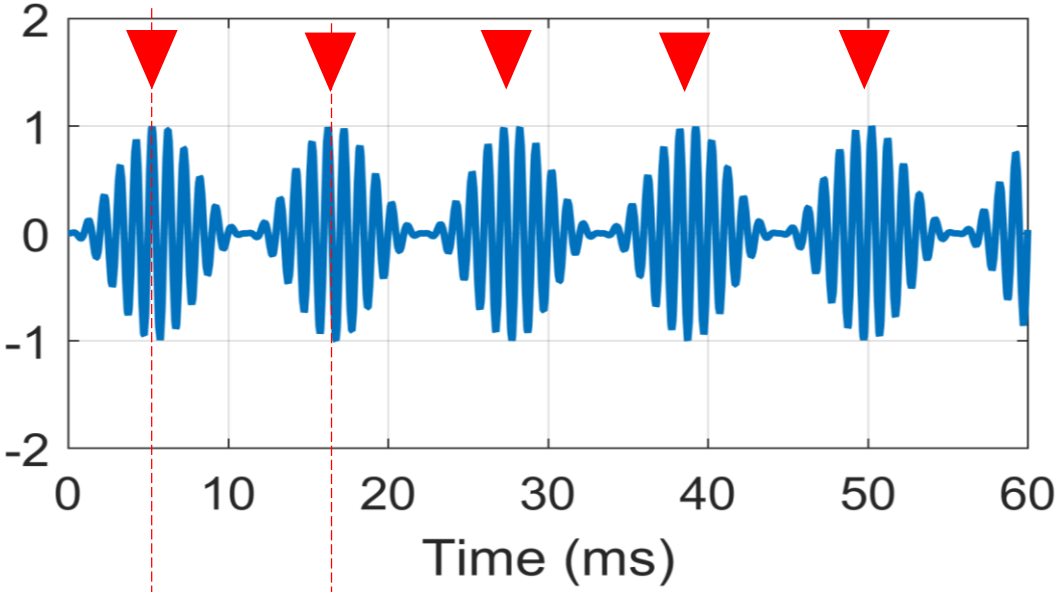
Noise exposure background

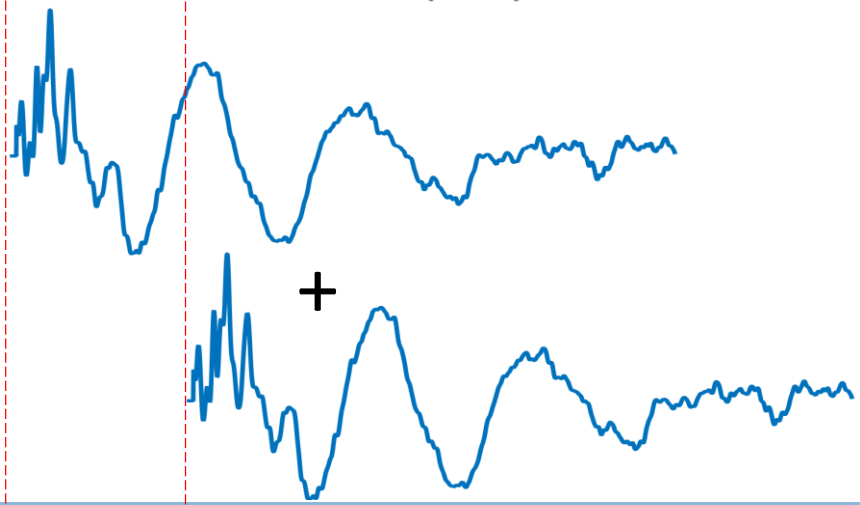
Research Paper

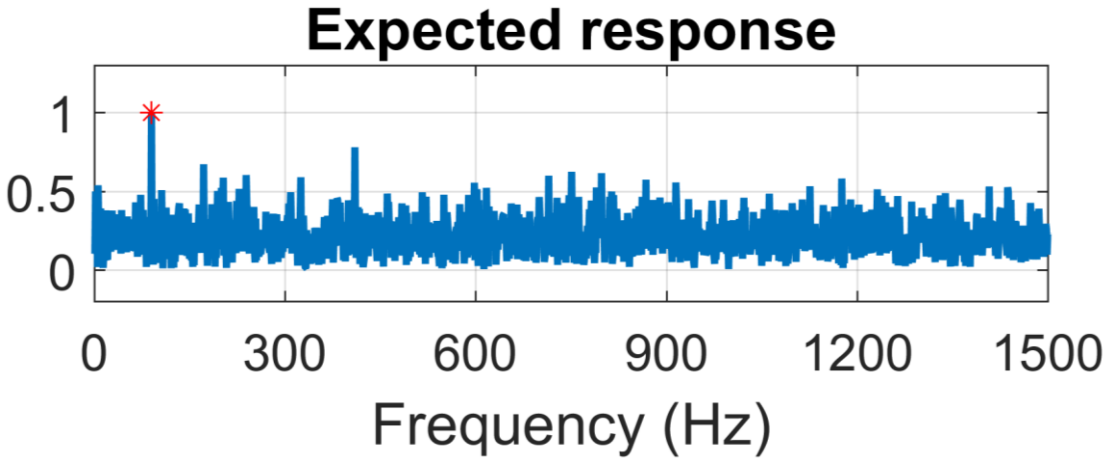
Effects of noise exposure on young adults with normal audiograms I: Electrophysiology

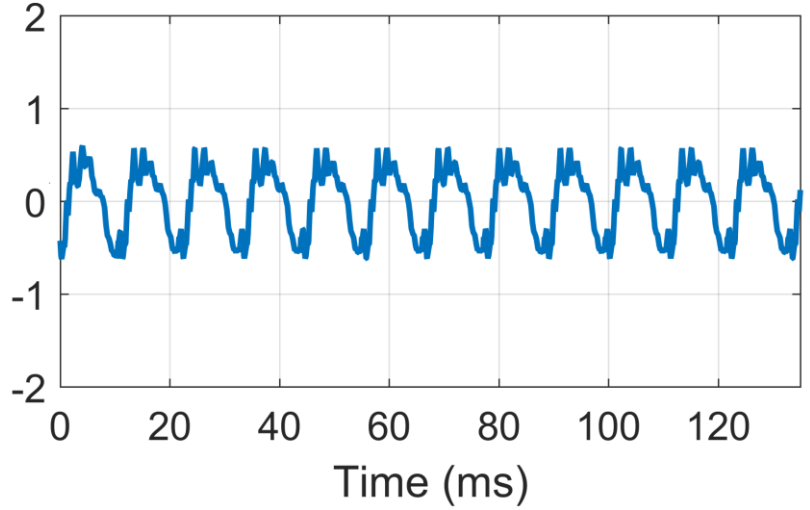
Garreth Prendergast [a, *], Hannah Guest [a], Kevin J. Munro [a, b], Karolina Kluk [a], Agnès Léger [a], Deborah A. Hall [c, d], Michael G. Heinz [e], Christopher J. Plack [a, f]

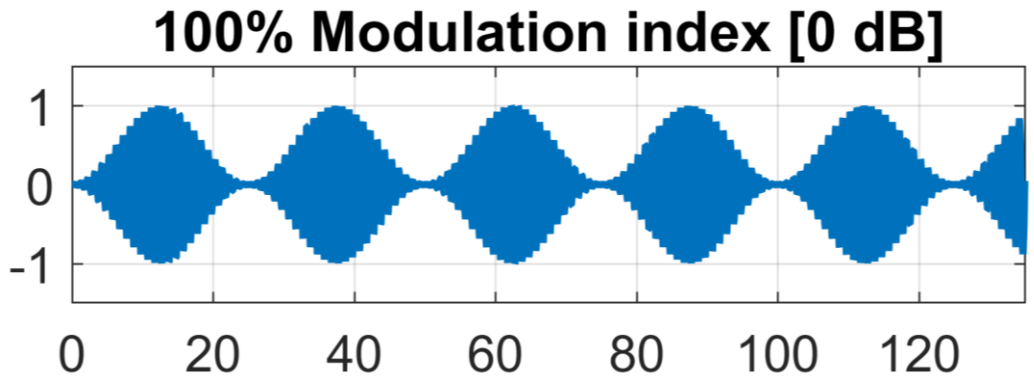
Biomarker 2 – EFR / ASSR

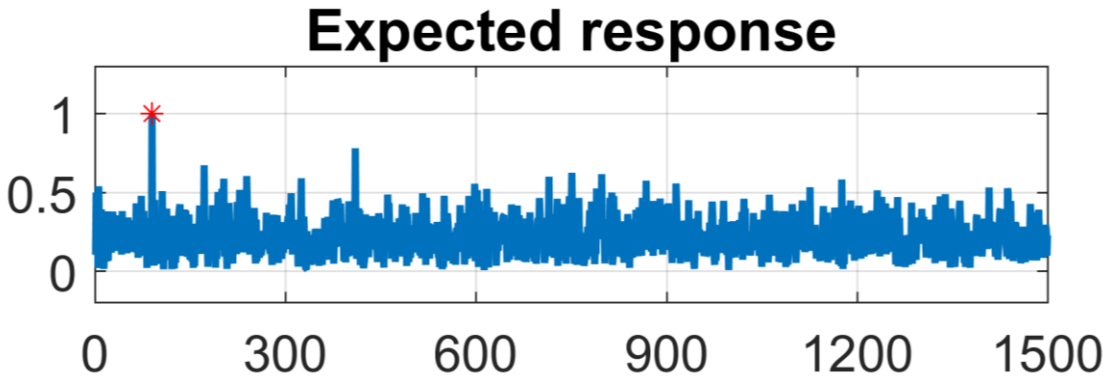


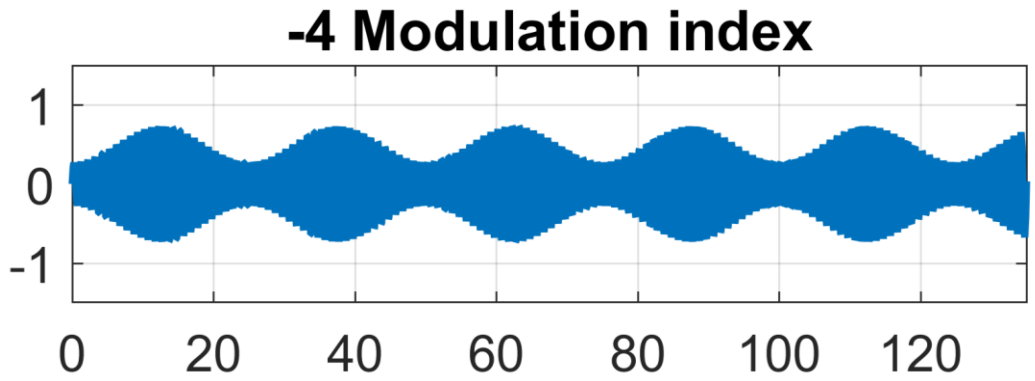


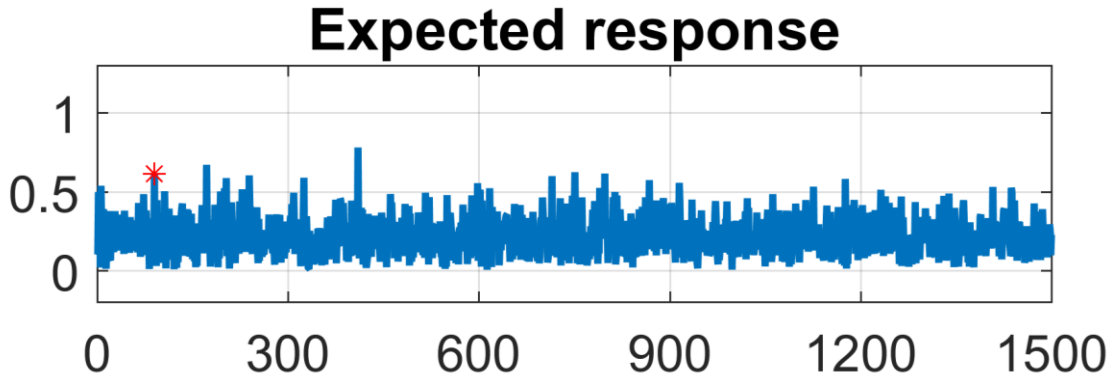


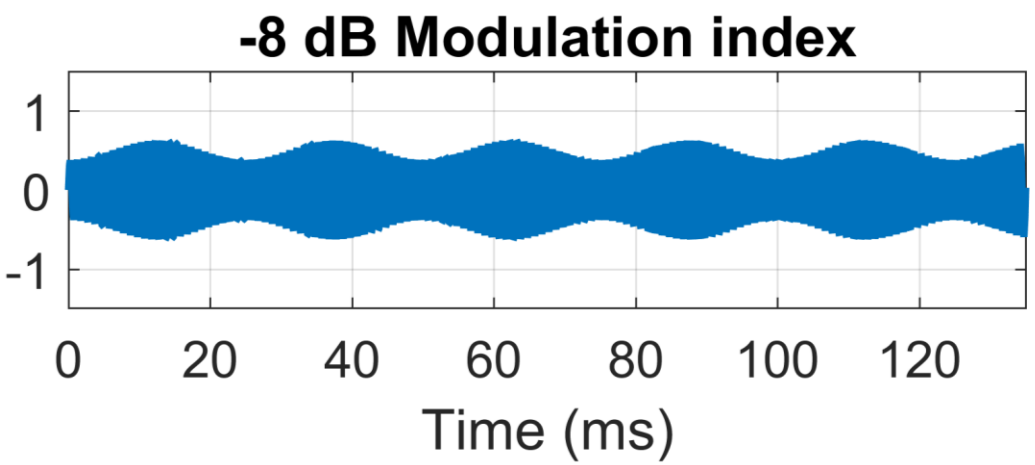


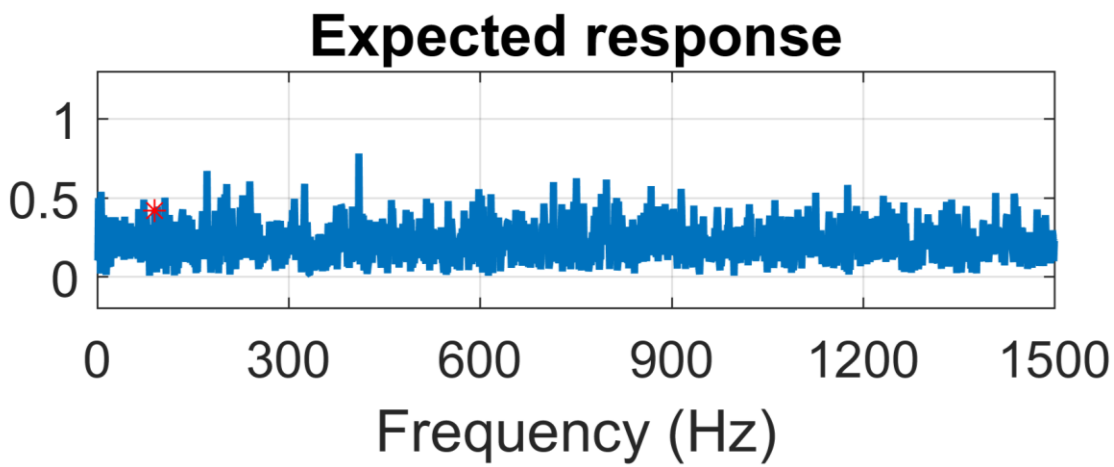

100% Modulation index [0 dB]
1
0
-1
0
20
40
60
80
100
120


Expected response
1
0.5
0
0
300
600
900
1200
1500


-4 Modulation index
1
0
-1
0
20
40
60
80
100
120


Expected response
1
0.5
0
0
300
600
900
1200
1500

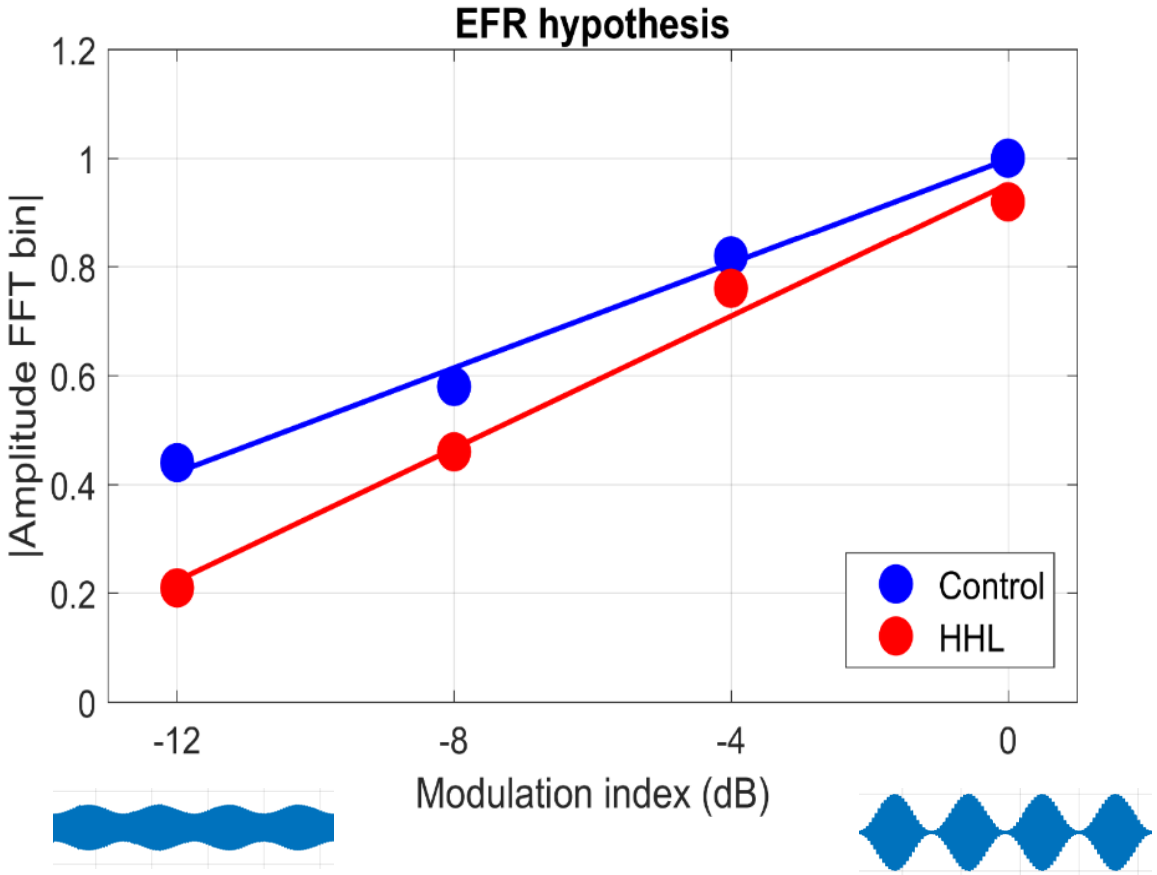

-8 dB Modulation index
1
0
-1
0
20
40
60
80
100
120
Time (ms)

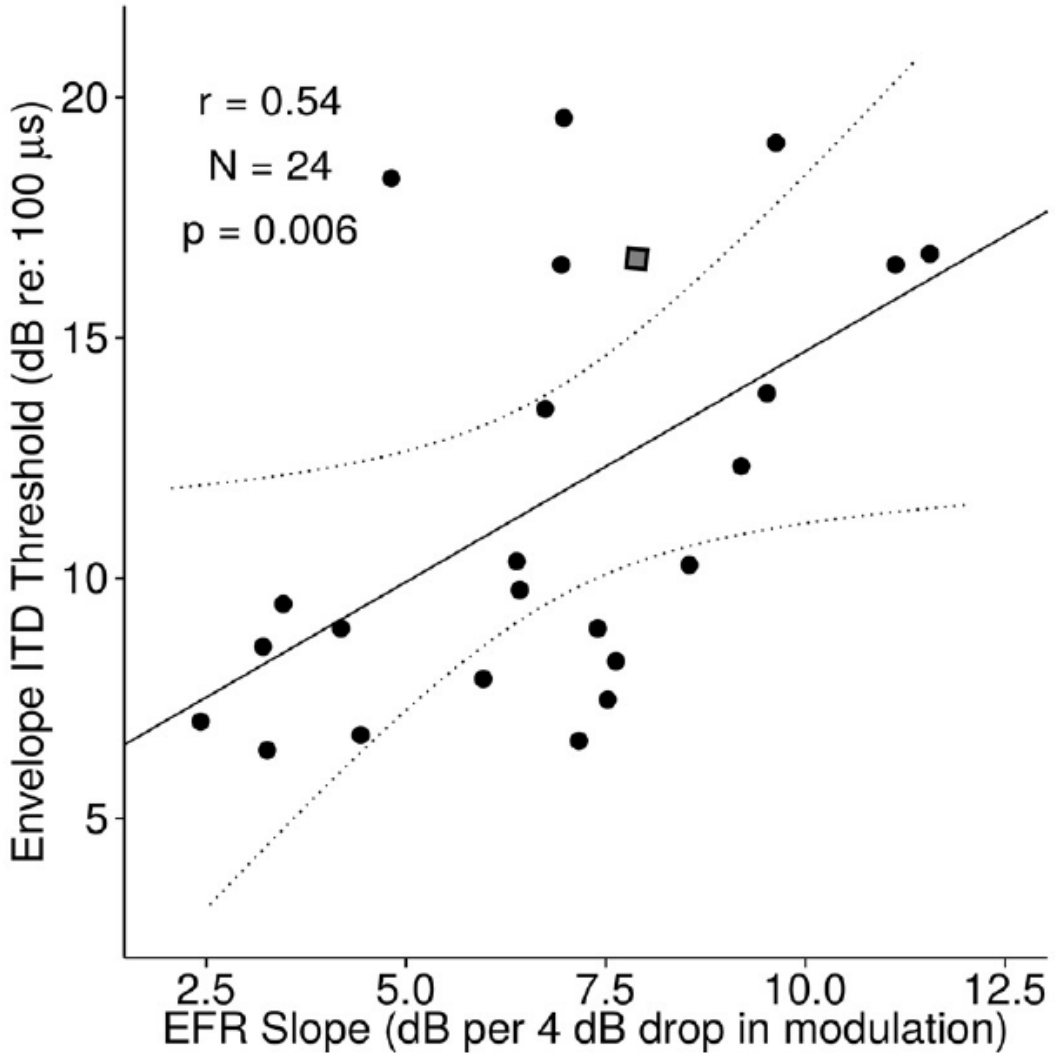

Expected response
1
0.5
0
0
300
600
900
1200
1500
Frequency (Hz)

The Journal of Neuroscience, February 4, 2015 • 35(5):2161–2172 • 2161

Individual Differences Reveal Correlates of Hidden Hearing Deficits

Hari M. Bharadwaj,[1,2] Salwa Masud,[1,2] Golbarg Mehraei,[1,3] Sarah Verhulst,[1,4] and Barbara G. Shinn-Cunningham[1,2]

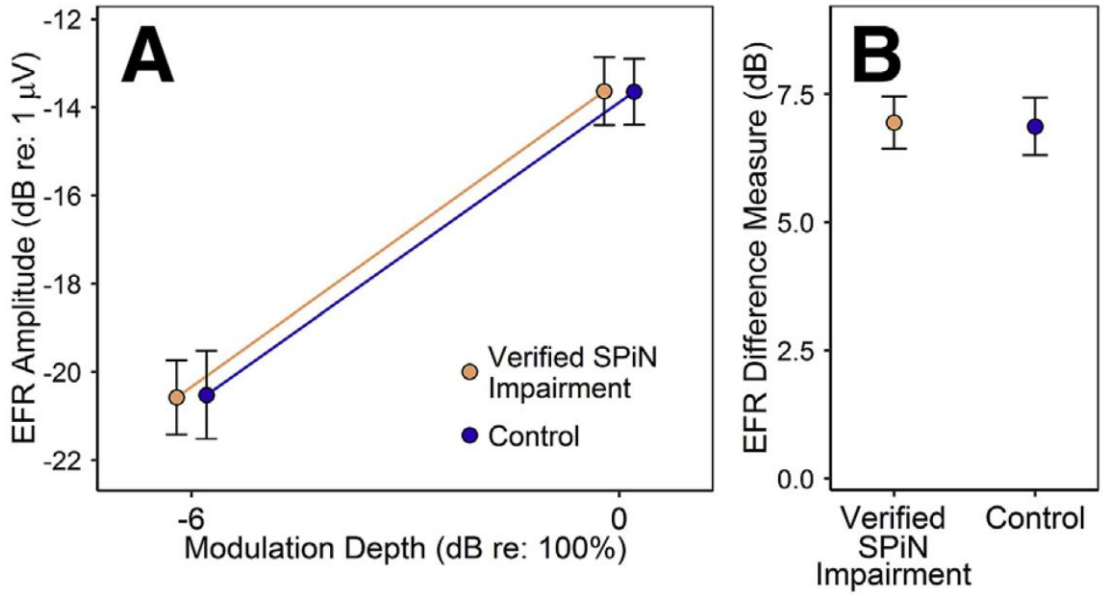




Research Paper

Impaired speech perception in noise with a normal audiogram: No evidence for cochlear synaptopathy and no relation to lifetime noise exposure

Hannah Guest [a, b, *], Kevin J. Munro [a, b], Garreth Prendergast [a, b], Rebecca E. Millman [a, b], Christopher J. Plack [a, b, c]



EFR not associated with speech-in-noise hearing performance

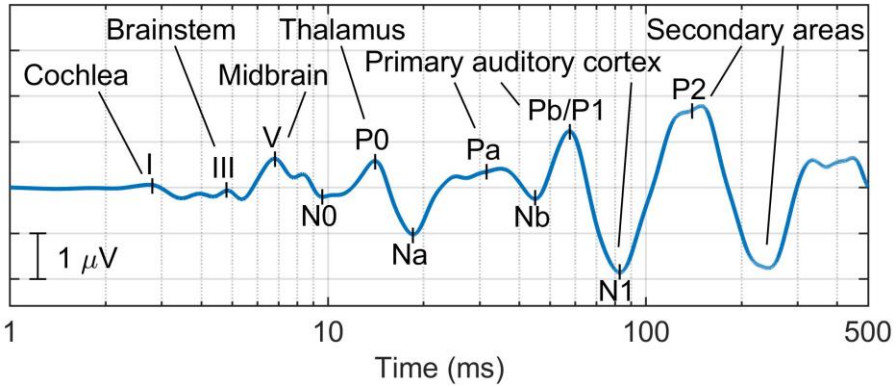
Future trends

BARRIERS

1. Focus on cochlear synaptopathy
2. Low sensitivity to SiN problems
3. Large inter-subject variability

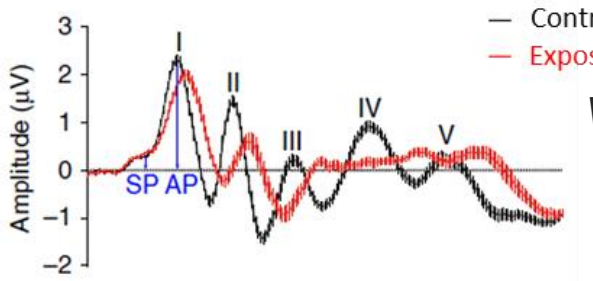
POSSIBLE SOLUTIONS

1. Target multiple pathologies
2. Increase sensitivity to SiN
3. Reduce inter-subject variability

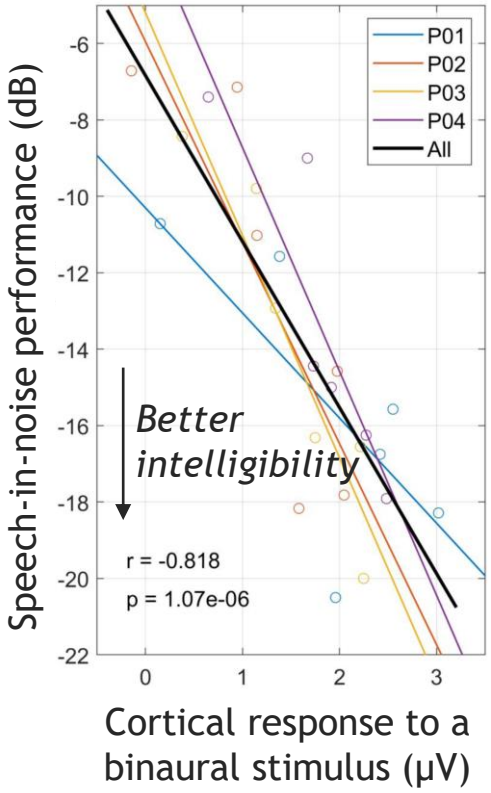


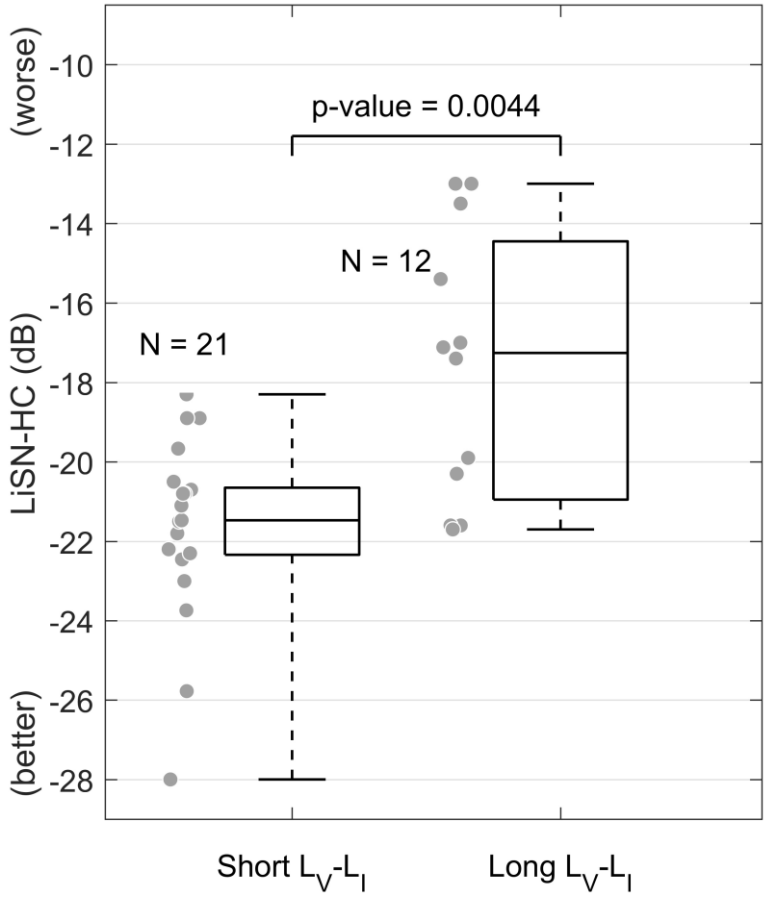
Full-range AEP
de la Torre, Valderrama et al. (2019)

Effect of demyelination



Wan and Corfas (2017)





Inter-peak latencies
Valderrama et al. (2018)

Part 4 – Management of hearing difficulties

Part 1 – Problem statement

Part 2 – Underlying mechanisms (animal models)

Part 3 – Diagnostic of HHL
- ✓ Existing biomarkers
- ✓ Forthcoming research

Part 4 – Clinical management
- ✓ Therapeutics interventions
- ✓ Low-gain hearing aids
- ✓ AirPods Pro hearables

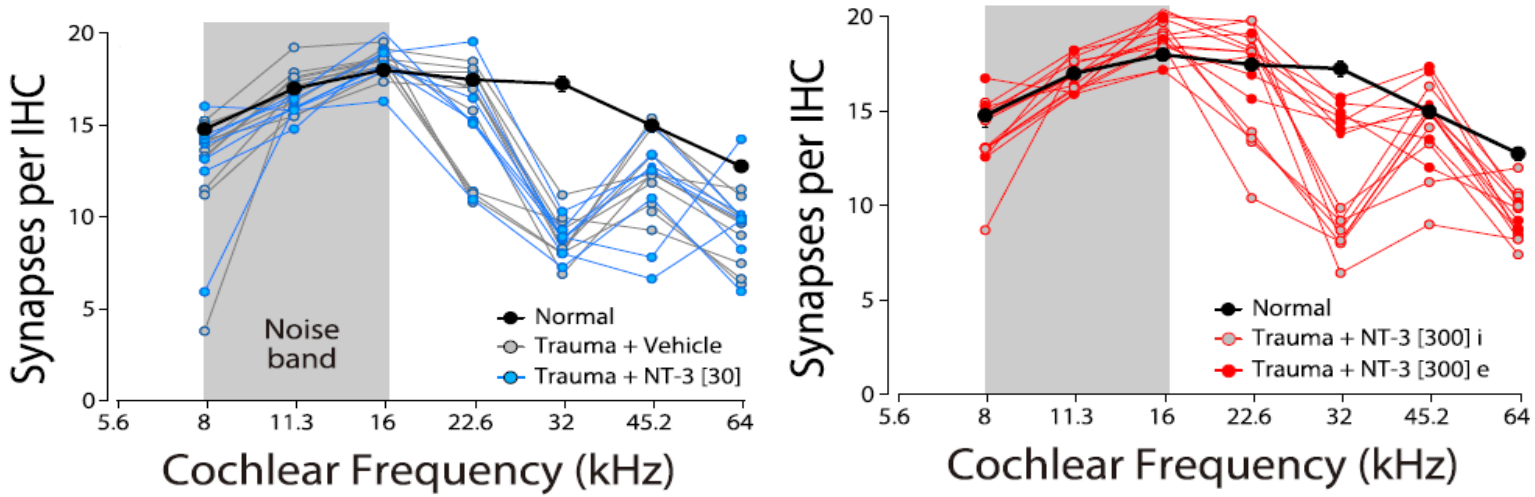
SCIENTIFIC REPORTS

OPEN

Received: 11 January 2016
Accepted: 04 April 2016
Published: 25 April 2016

Round-window delivery of neurotrophin 3 regenerates cochlear synapses after acoustic overexposure

Jun Suzuki[1,2,3], Gabriel Corfas[4] & M. Charles Liberman[1,2]



Relevant questions

- To what extent these devices improve the hearing experience of their users?
- What are the listening scenarios in which devices perform best/worse?
- What proportion of users benefit when using these devices in challenging venues?
- What are the characteristics of those who benefit from these technologies?
- What are the main barriers that would discourage users from using the devices?

NAL Study 2. Mild-gain hearing aids
Phonak M50

NAL Study 3. Hearables
Apple AirPods Pro

NAL Study 1 – Mild-gain hearing aids

Manuscript in preparation

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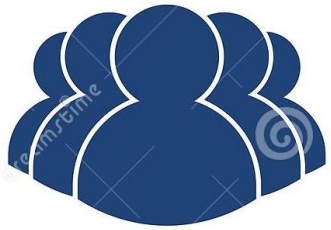
Methods

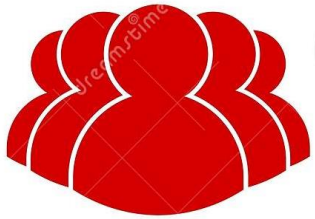
A double-blinded **randomised controlled trial**

Control



- 14 participants
- 9 females
- [19,63] yr
- Mean = 40.8 yr
- **0 dB gain**

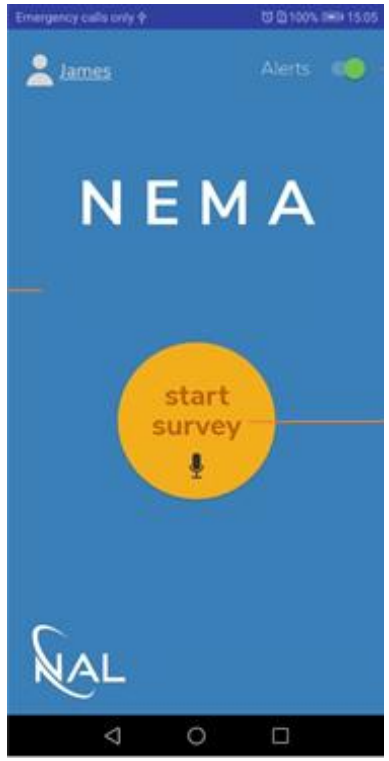
Experimental



- 13 participants
- 8 females
- [31,63] yr
- Mean = 44.8 yr
- **+8 dB gain**

Start — 6 weeks NEMA — 6 weeks NEMA — **End**

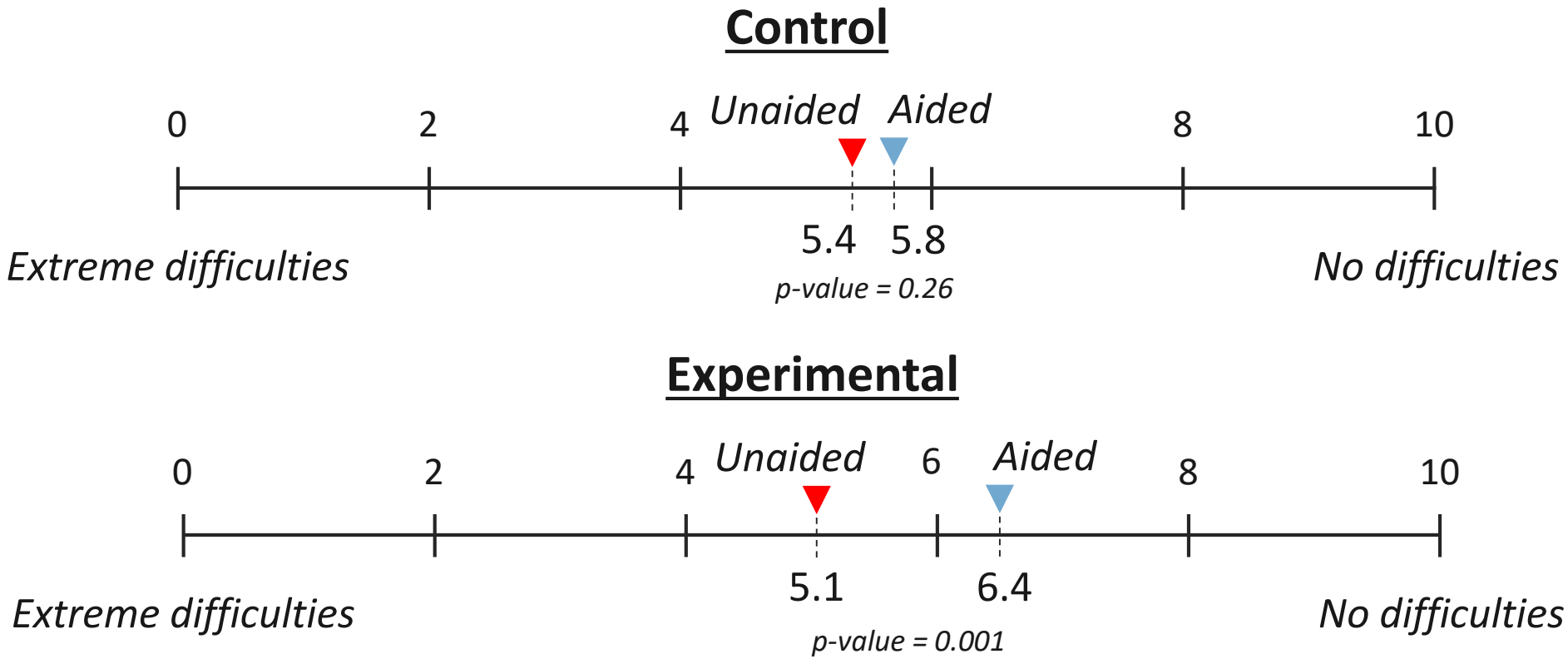
- SSQ-Unaided
- HA fitting
- SSQ-Aided
- SADL
- Open-ended Q



NEMA surveys

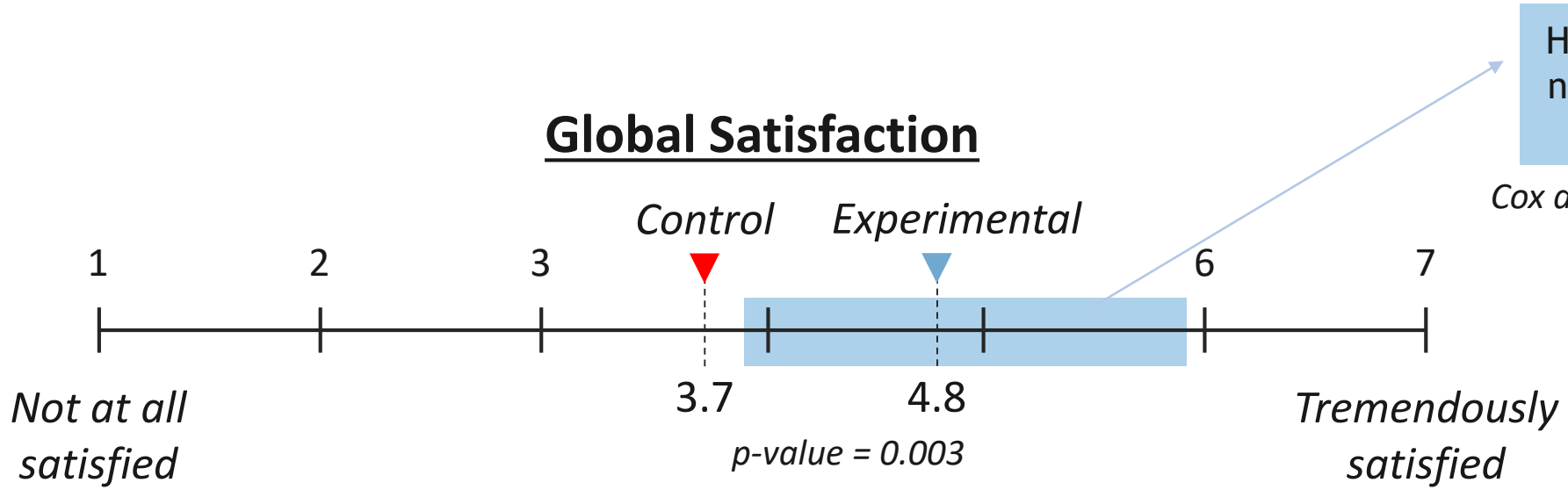
- Understand
- Participate
- Frustration
- Benefit
- Satisfaction
- Noise level

Self-perceived hearing difficulties (SSQ)



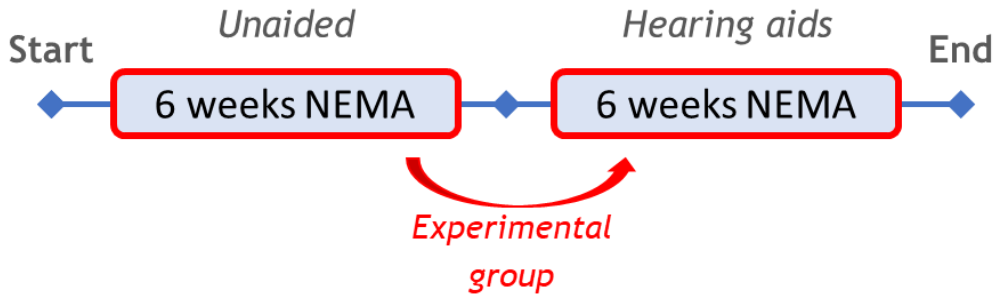
Low-gain hearing aids reduced self-reported speech-in-noise hearing difficulties

Hearing aids satisfaction (SADL)



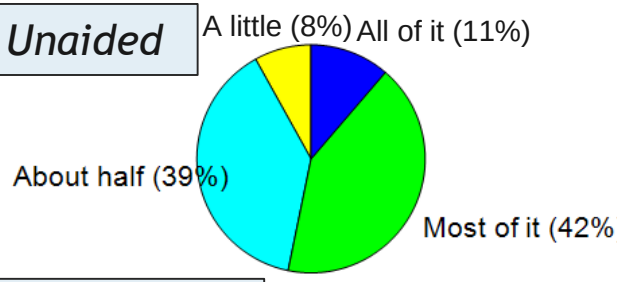
Providing a mild gain increases global satisfaction from 'medium satisfied' to 'considerably satisfied'

Real-life assessment (NEMA)

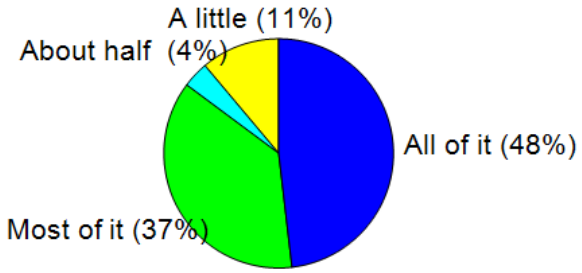


Understanding

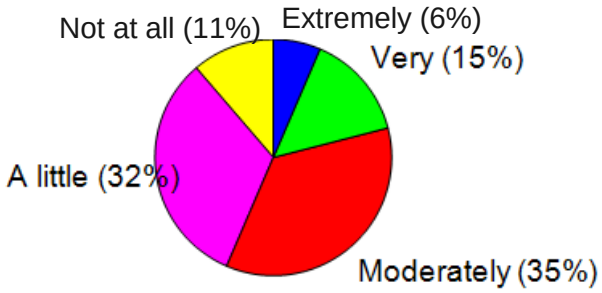
Unaided

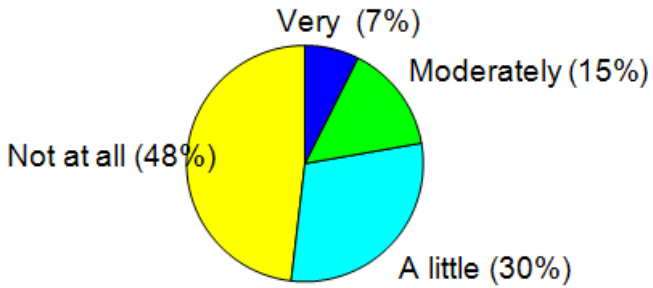


Hearing aids

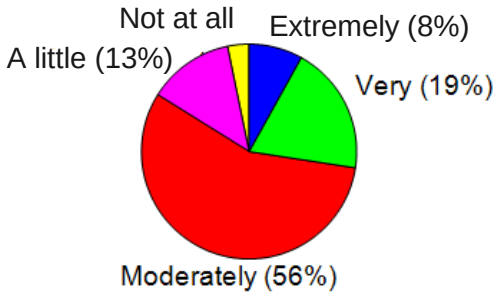


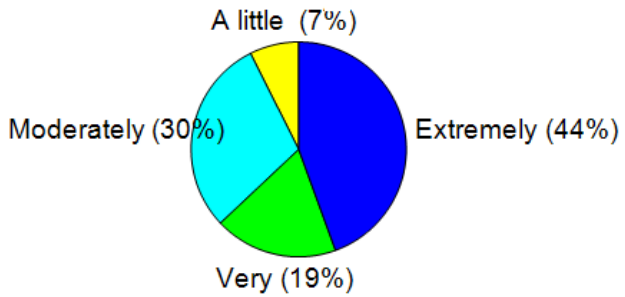
Frustration



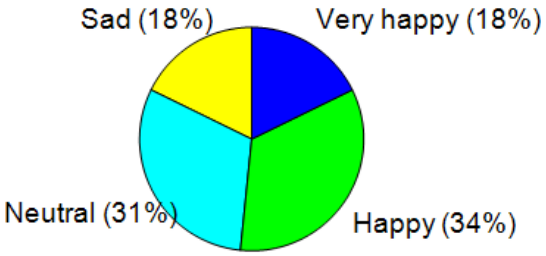


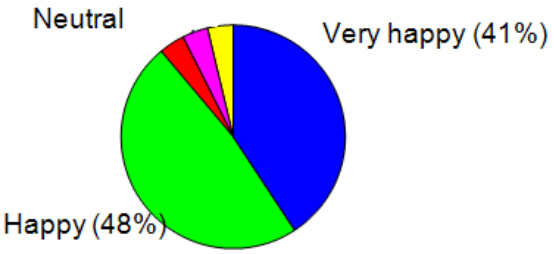
Participation





Mood





Low-gain hearing aids helped participants to understand more, participate more in conversations, reduce their frustration, and improve their mood in real-life noisy conversations

Would you continue using the hearing aids?

Control: 9/14 NO
Experimental: 8/11 YES

No. Unnoticeable benefit, for the slight administrative burden (batteries management, fitting comfort, etc.)

I would consider it **if my hearing loss gets a lot worse**, but at this stage the cons outweigh pros

No. They don't really help

No

No, I don't feel it has been a distinctive change enough for me

Control

I would only want to wear them **in particular environments** requiring a lot of listening - this would help reduce fatigue and frustration

Yes, the benefit that I gain from them is too great to not use them

Yes but they do appear to have improved my condition

Yes I would in social situations. It makes engaging in conversations easier

Yes, would be a useful option to have when going into noisy social/talking environments

Experimental

No because **I don't think I need them at this stage** and they're a bit awkward (slightly itchy, tickly and make it harder to change glasses especially if also wearing a mask and earrings). I don't like hearing myself eat

Would you purchase the hearing aids?

Control: 14/14 NO
Experimental: 11/11 NO

Not at this stage as it is too expensive, but I would if my hearing impacts my ability to work

No

No. I don't feel any improvement in my hearing ability

Control

At a cost of $5000 I would personally **not be investing** in hearing aids as I find my unaided hearing to work well, even if I sometimes struggle in a noisy environment to understand speech clearly

No. Too much money!

Not for that price

Experimental

NAL Study 1 summary

- Low-gain hearing aids improve the hearing experience of individuals with normal audiograms but with speech-in-noise hearing difficulties
- Participants fitted with 8 dB gain hearing aids could understood more in noisy venues, participate more in conversations, and reduce their frustration
- The elevated cost is a barrier for the adoption of hearing aids for this population

NAL Study 2 – AirPods Pro hearables

Manuscript under review

The value of Apple AirPods Pro ~~on the management of~~for managing speech-in-noise hearing difficulties ~~reported by~~of individuals with ~~a~~normal audiograms

[Names] Joaquin T. [Surname] Valderrama[a,b,*], [Name] Jorge [Surname] Mejia[a,c], [Name] Angela [Surname] Wong[a], [Name] Nicky [Surname] Chong-White[a,c], [Name] Brent [Surname] Edwards[a,b]

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Word count: 8,500 words.

Number of figures: 5 figures.

Number of tables: 1 table.

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Brent Edwards
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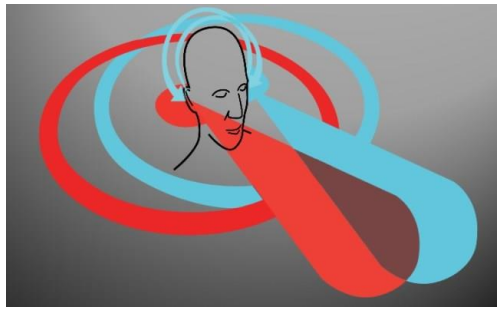
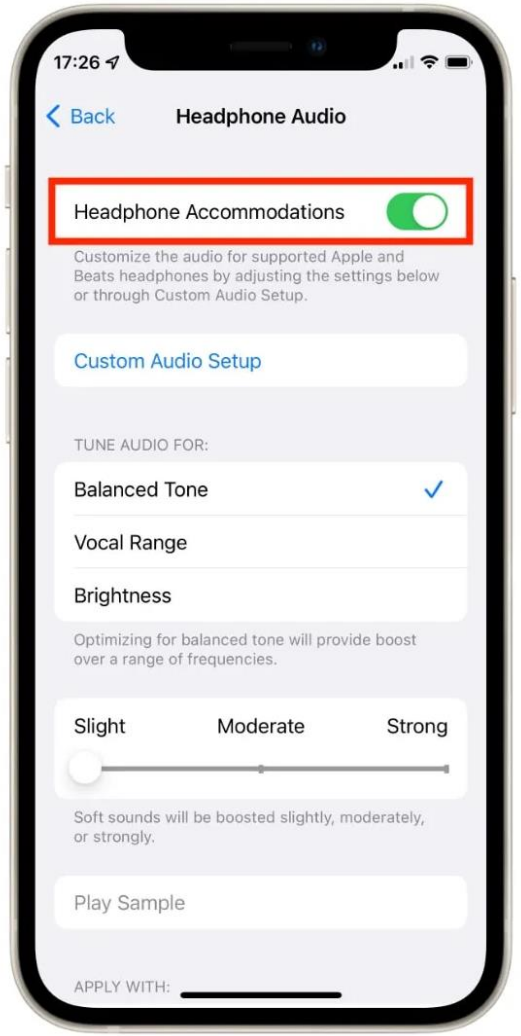
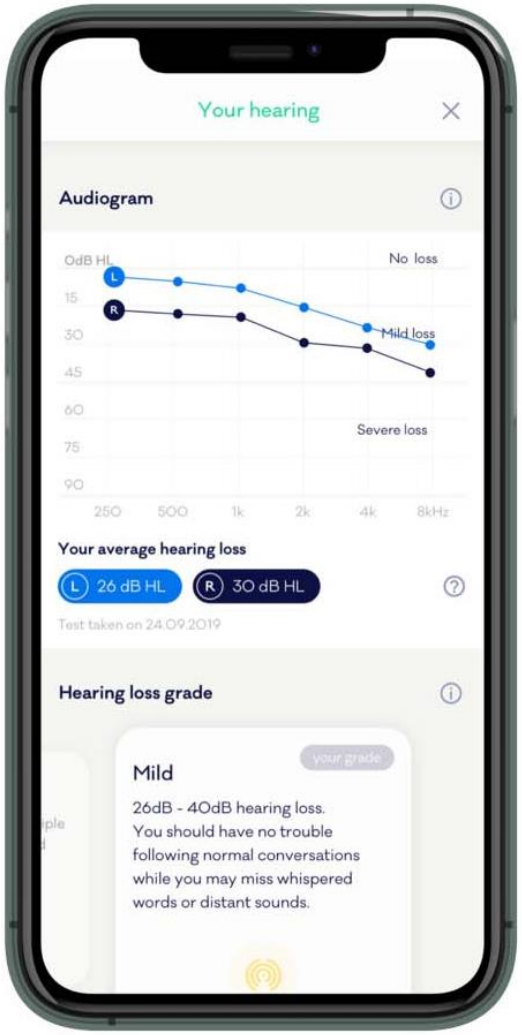
Methods



iOS 15 features

- Headphone Accommodations
- Conversation Boost
- Ambient Noise Reduction



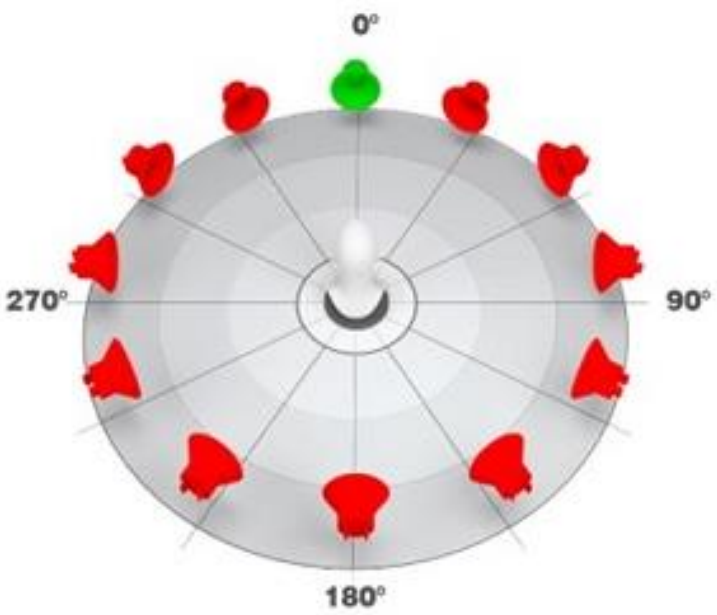


Methods

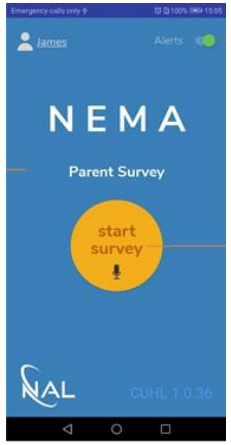
- 17 participants
- 21-59 years
- 9 females

- Personalized audiograms
- Ambient Noise Reduction MAX
- Conversation Boost ON

Speech-in-noise performance

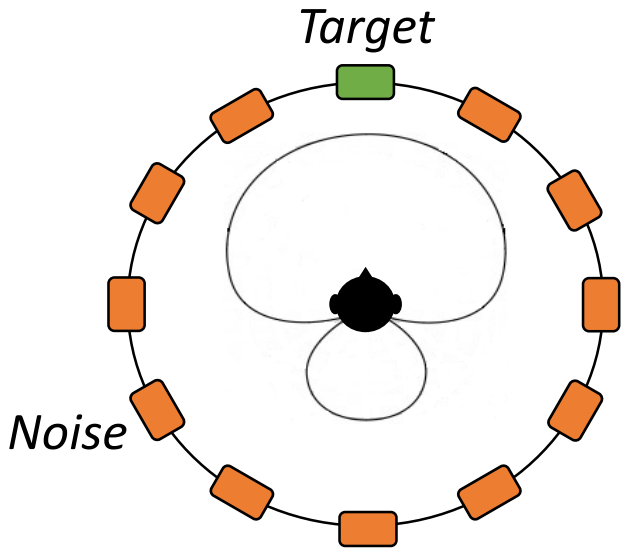


Real-life measures

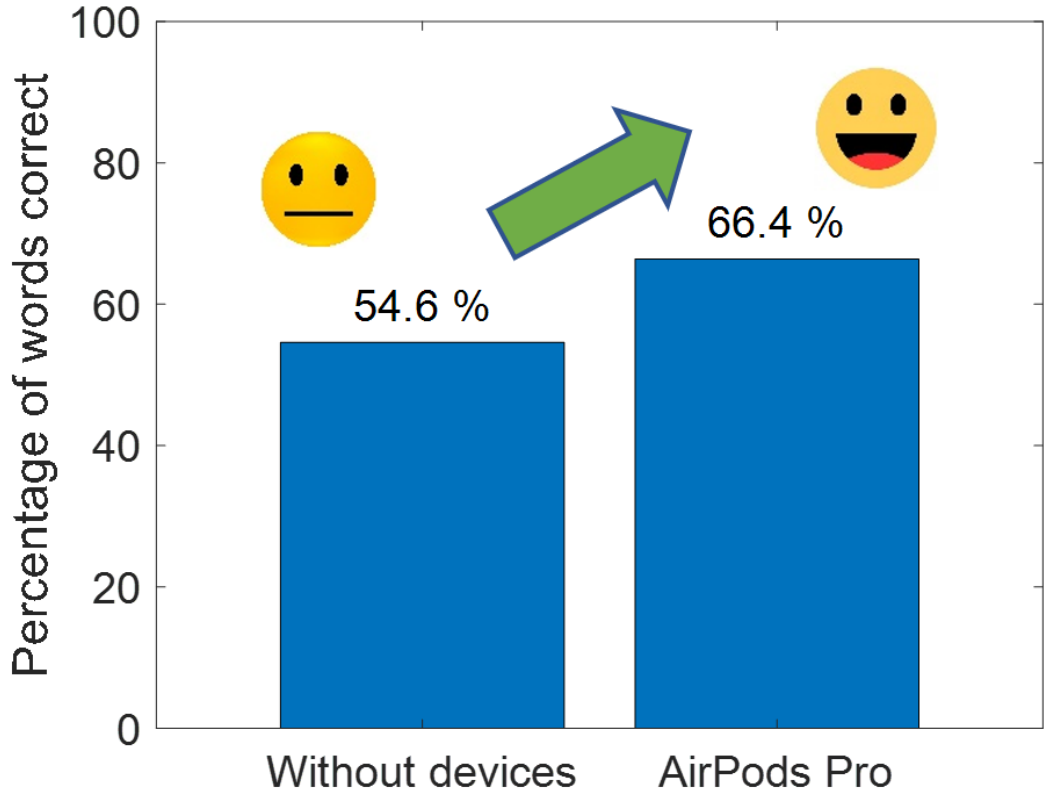


Questionnaires

Speech-in-noise performance

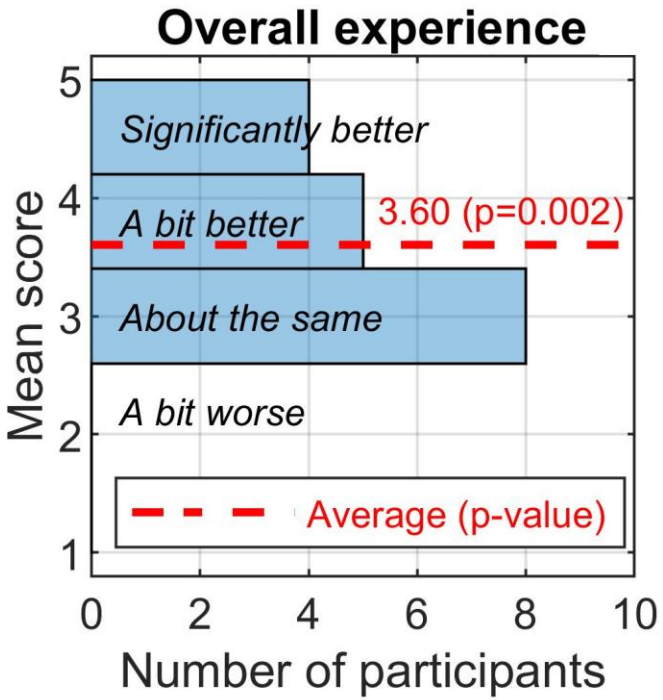


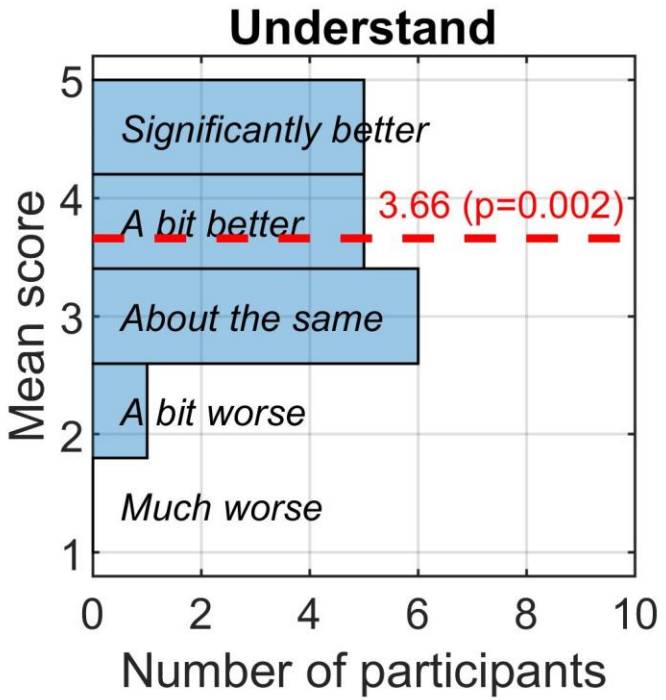
- 16 speakers array, 2.7 m diameter
- Target speech: BEST test (Best et al. 2014, 2018)
- Diffuse noise multi-talker speaker, 65 dB SPL
- SNR corresponding to 50% intelligibility
- Participants *unaided* and *wearing AirPods Pro*

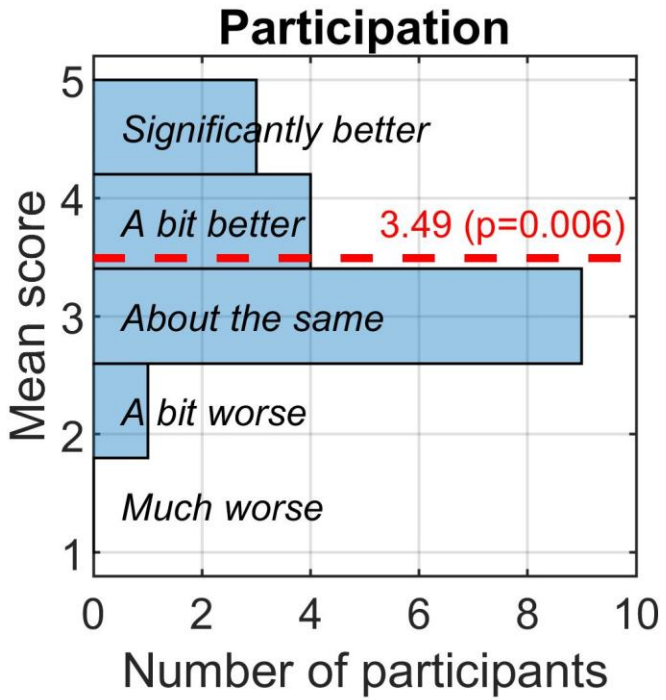


AirPods Pro provided around 11% speech-in-noise intelligibility improvement

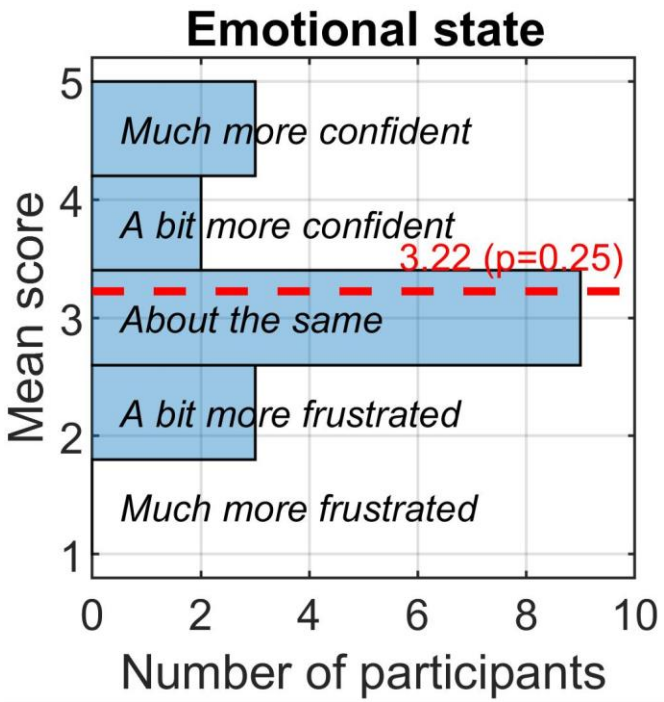
Real-life assessment (NEMA)

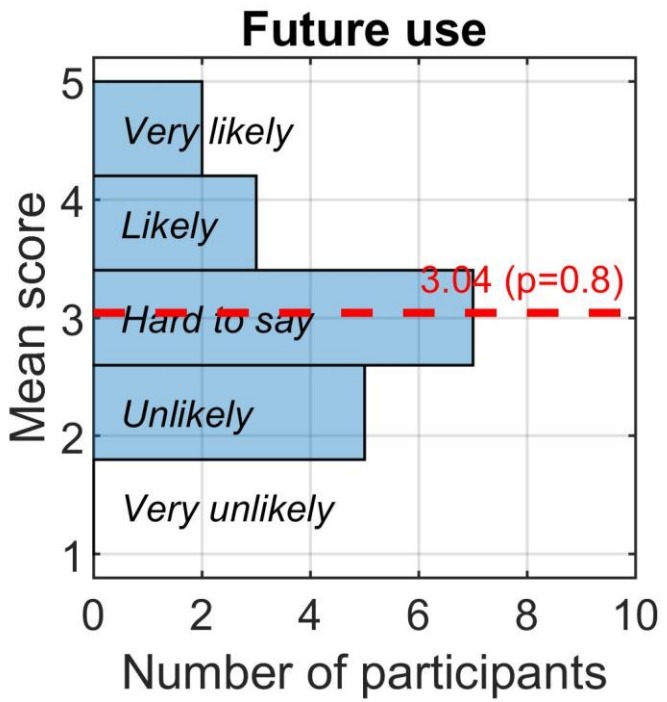






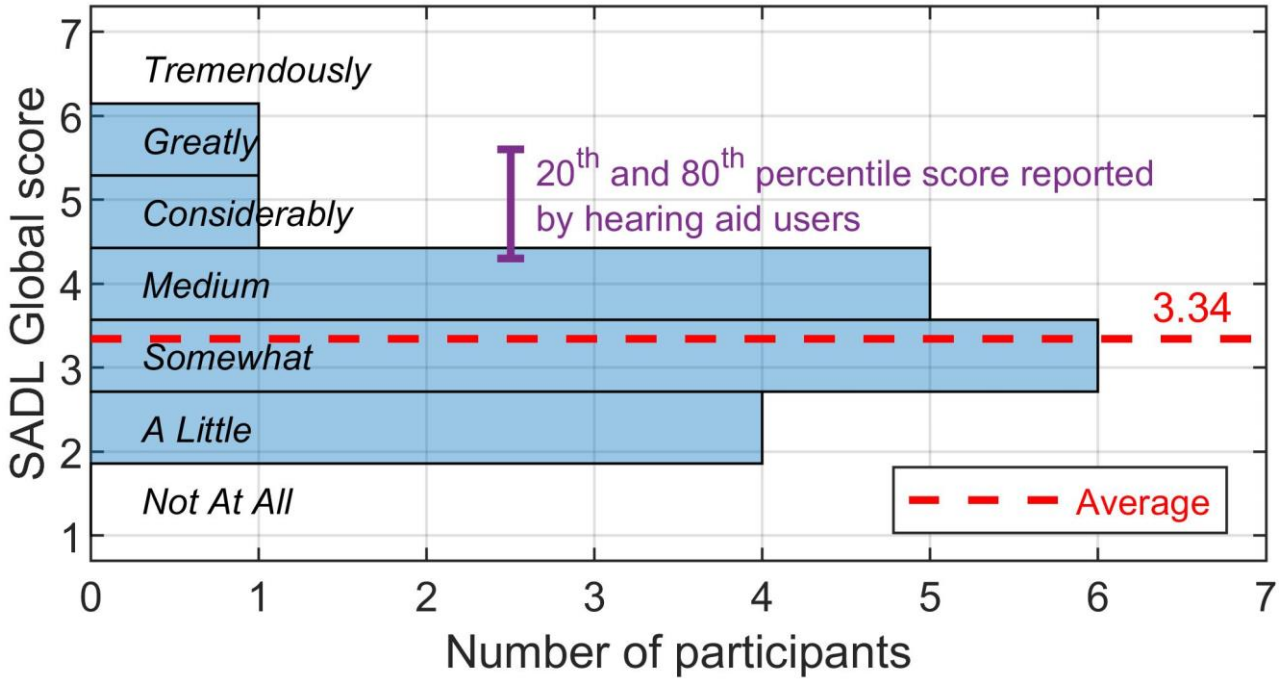
Real-life assessment (NEMA)



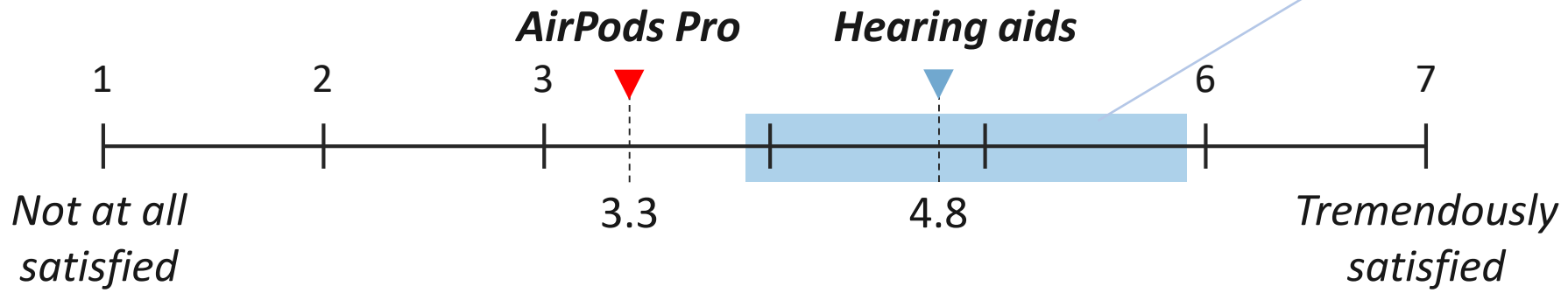


Barriers	Surveys
Limited hearing benefit	55
Uncomfortable to wear	35
Feeling embarrassed	27

Satisfaction with the devices (SADL)



Hearing aid users normative scores 4.9 ± 1.0



End-of-study questionnaire

To what degree do AirPods Pro improve your hearing experience in noisy places?

7/17 (41%) – Not much

There is some improvement but it is minimal. When it is windy (e.g. for outside events) the AirPods Pro actually make the wind noisier and negatively impact your conversations.

7/17 (41%) – Depended on the ambient sound

My experience was inconsistent. In one on one situations they performed better compared to group gatherings. In other occasions, sounds like the rubbing of my hair against the AirPods Pro and the sound of my chewing were amplified, whereas other background sounds were not.

3/17 (18%) – Positive experience

I could hear voices much more clearly in close proximity as well as some distance away. **I felt more engaged in the conversations** because I could hear better. The ability to hear people at the dinner table at a noisy restaurant is probably the most beneficial.

End-of-study questionnaire

Positives

Comfortable to wear

Long battery life

Easy pairing with iPhone

Beautiful design

Inexpensive

Small and unobtrusive

Multi-purpose

Negatives

Hearing their own voice, walking or chewing

Limited hearing-in-noise benefit

Uncomfortable for long-time use

Unnatural amplification of background and wind noises

Societal and stigma – they are not perceived by others as assistive listening devices

I did not feel at all embarrassed wearing them, but **a few people asked me about them and why I was wearing them**. In the trial it was easy to explain the scientific nature of the trial, but this might become irritating if long term use. It was potentially perceived by others that you were listening to music or doing other things whilst in a group or conversation. Also, **I don't think their hearing correction worked so well outside**, in a loudish area on a beach with plenty of ambient environmental noise.

End-of-study questionnaire

Would you continue using AirPods Pro in similar situations in the future?

5/17 (30%) – Yes

I would continue using AirPods with family and friends in group environment and / or work mates and associates in a work environment who know the purpose of the AirPods. Explaining the purpose of the AirPods would be problematic for me in most other environments with people I am not directly associated with.

12/17 (70%) – No

I would not use them in conversations. People think that you are ignoring them if they see you using them and the impact on the quality of the conversation is not significant.

- Limited benefit
- Comfort
- Societal – stigma

Take-home messages & Acknowledgments

- HHL affects a significant proportion of the population, with important implications in the quality of life of people who experience these difficulties and their clinicians.
- Animal models show that different pathologies could be involved in HHL in humans, including cochlear synaptopathy, auditory nerve demyelination and neural maladaptation.
- Currently, the search for a non-invasive biomarker of HHL in humans continues. Several methodological challenges need to be addressed, including the large inter-subject variability of existing metrics and their low sensitivity to speech-in-noise hearing problems.
- Intervention options based on low-gain hearing aids and hearables provide some degree of hearing benefit, but barriers such as cost, comfort, stigma, and not enough hearing benefit are preventing a widespread adoption of these technologies.

frontiers | Frontiers in Neuroscience

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The hunt for hidden hearing loss in humans: From preclinical studies to effective interventions

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