Untersuchungen des CI-basierten Hörens mittels funktioneller Nahinfrarotspektroskopie (fNIRS)

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Introduction

Introduction

- Objective assessment of CI-based hearing using combined fNIRS and EEG measurements
- Especially important in *young children*: Can we find out how well these children can hear before we can ask them?
- Establishing *fNIRS as a diagnostic tool* in clinical practice

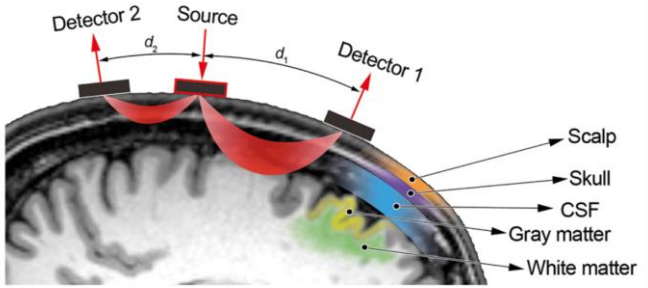
Cochlear implants

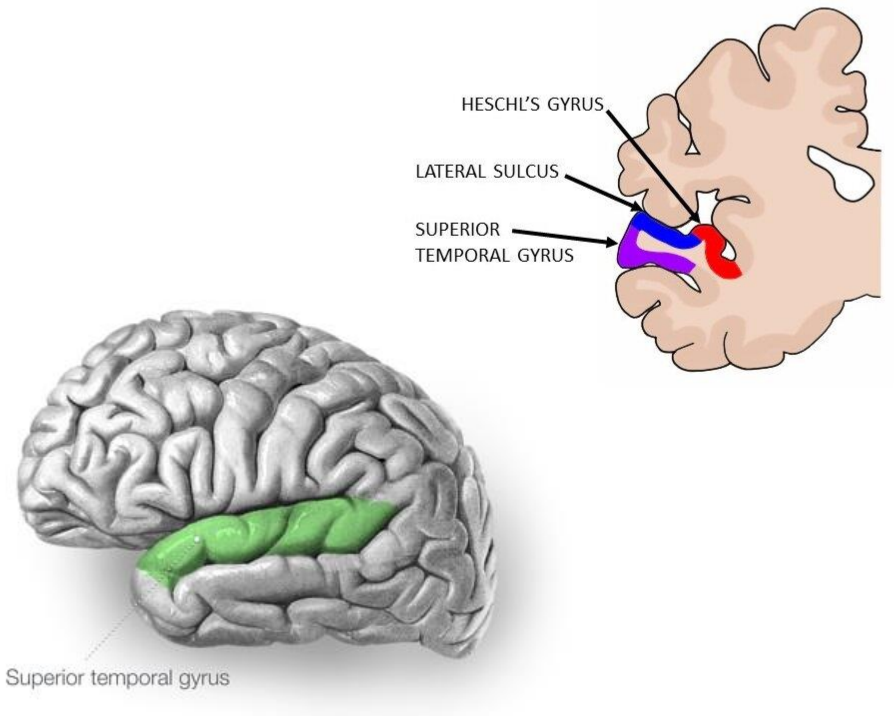
- CIs are surgically implanted devices that directly stimulate the auditory nerve via an inserted electrode array

- CIs are still the only successful sensory prosthesis used in humans and enable even deaf children to acquire language

- A fundamental limitation when listening through a CI is that the access to pitch information is severely limited

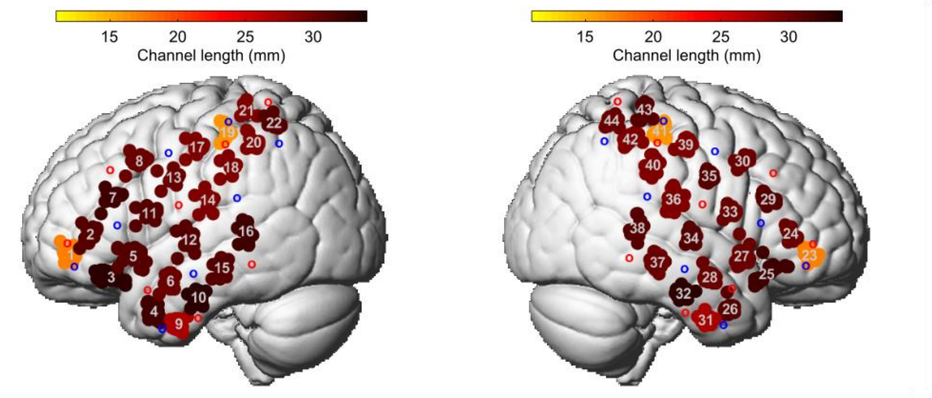
fNIRS

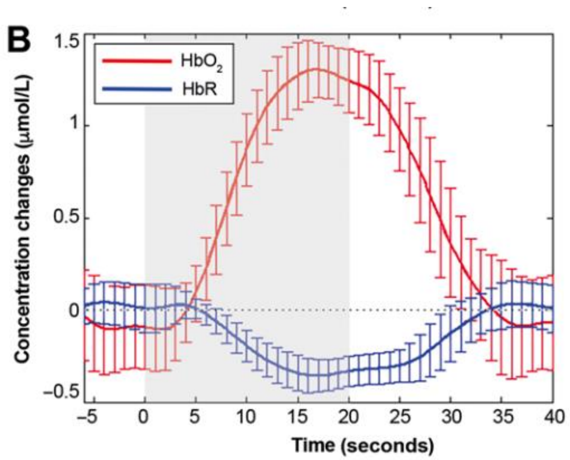




- *Functional near-infrared spectroscopy* (fNIRS) allows the measurement of activity in superficial cortical regions, such as STG
- Deeper sources such as Heschl's gyrus are out of reach
- Used *short channels* to limit the influence of systemic artefacts
- Easy to use and unaffected by the electrical signals of cochlear implants (CIs)

fNIRS

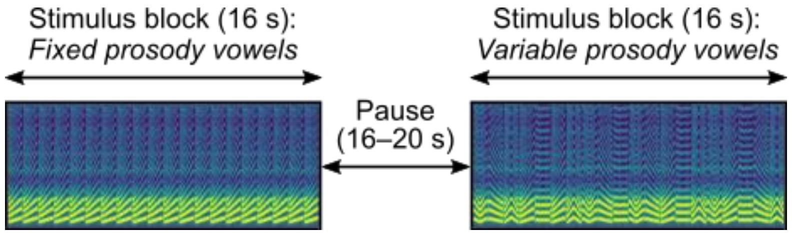


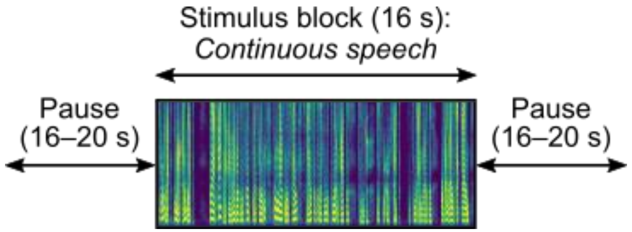


- Used 3D localiser to accurately determine the fNIRS sensor positions and corresponding cortical areas
- Focussed on *HbR data* as HbO data often unreliable when studying auditory activity (*Steinmetzger et al., 2020, HearRes,* https://doi.org/10.1016/j.heares.2020.108069)

- fNIRS and EEG data can be obtained simultaneously allowing cross validations
- EEG source localisations to *validate* the fNIRS results

Stimuli and paradigm

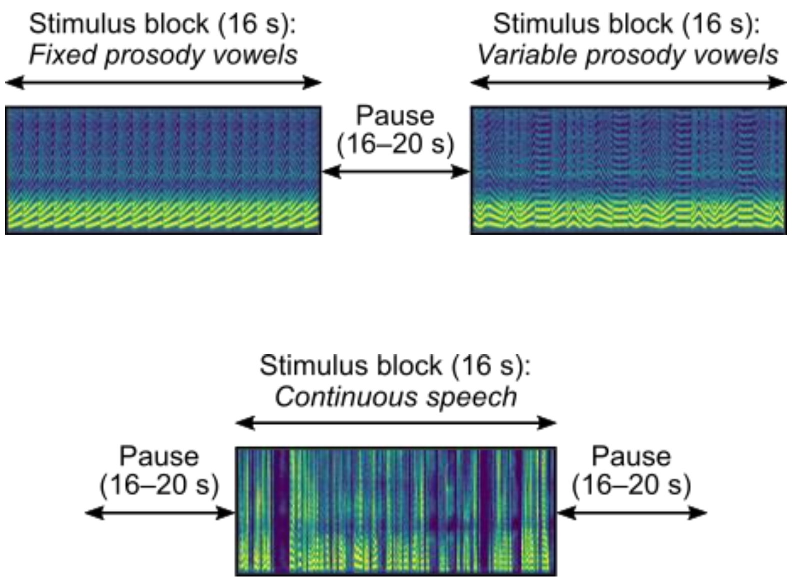




- Continuous vowel sequences in which the prosodic contours were either the same throughout *(Fixed)* or varied between vowels *(Variable)*
- Block design without behavioural task
- Difference between fixed and variable conditions obvious with normal hearing, but at best subtle when listening through CIs

- Paediatric CI users additionally tested using continuous unprocessed speech

Research questions



- →Is fNIRS suited to detect relatively subtle prosodic differences?
- →Which ERP components reflect prosody processing?
- →How does speech-evoked cortical activity in pre-lingually deafened CI users change with more CI experience?
- →Is fNIRS really the method of choice for studying CI-based hearing?

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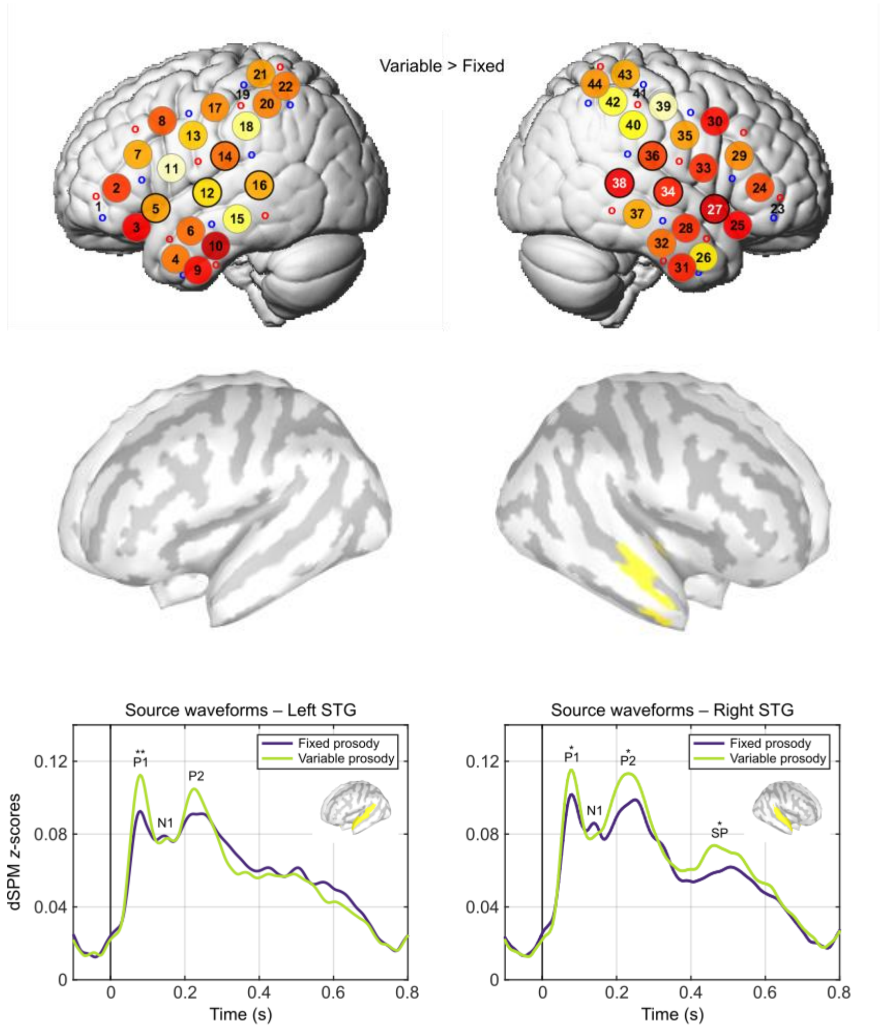
Results: I NH adults

I NH adults



- Commenced by testing 20 young normal-hearing (NH) listeners to obtain a “standard model” of cortical activity

- fNIRS results showed stronger activity along the right STG in the variable prosody condition
- ERP source localisations showed a similar pattern
- Difference driven by larger P2 and sustained potential in right STG

Steinmetzger, 2022, HearRes
https://doi.org/10.1016/j.heares.2022.108483

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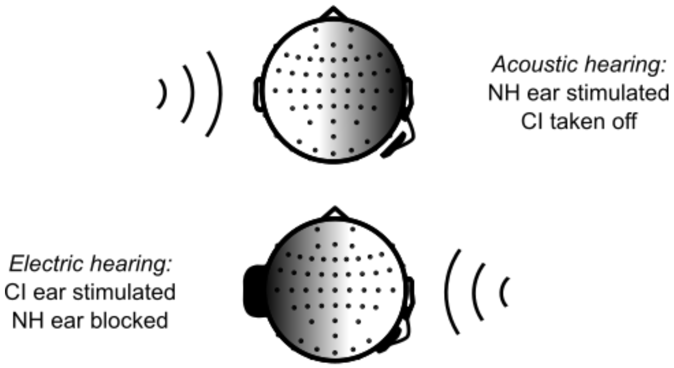
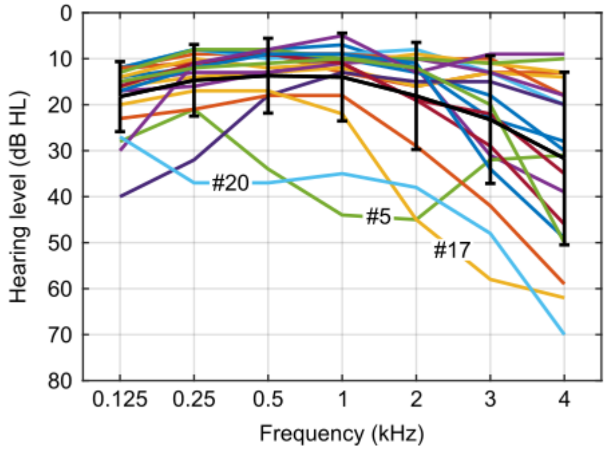
Results: II CI adults

II CI adults





- In a second step, we tested 20 unilateral adult CI users with preserved normal hearing in the other ear *(single-sided deafness, SSD)*

- Same stimuli and paradigm as before, but *separate sessions* for the normal and implanted ears
- Each subject served as *their own control*, enabling a direct comparison of acoustic and electric hearing
- Apart from a few exceptions, the audiograms of the normal ears only showed some age-typical hearing loss at high frequencies

Steinmetzger, 2022, NeuroImage: Clinical
https://doi.org/10.1016/j.nicl.2022.103188

II CI adults

Subject	Age	Sex	CI ear	Duration of deafness (~y)	Duration of CI use (y.m)	Aetiology of deafness	Implant & processor type / strategy	Words correct CI ear (%)
1	58	m	l	23	5.5	Intracochlear schwannoma	FLEX28 & OPUS2 / FS4-p	60
2	61	f	r	6	5.6	Acoustic neuroma	FLEX28 & OPUS2 / FS4	65
3	59	f	l	1	2.2	Sudden hearing loss	HiRes90K & Naida Q90 / HiRes Optima-S	45
4	66	f	r	26	2.6	Sudden hearing loss	FLEX28 & RONDO / FS4-p	65
5	66	f	l	22	5.6	Sudden hearing loss	FLEX28 & OPUS2 / FS4	10
6	67	f	l	1	5.2	Sudden hearing loss	CONCERTO medium & OPUS2 / FS4-p	45
7	66	m	r	1	6.1	Sudden hearing loss	CI422 & CP810 / ACE	70
8	55	f	r	39	6.1	Mumps	FLEX28 & OPUS2 / FS4	55
9	50	f	l	1	5.9	Sudden hearing loss	FLEX28 & OPUS2 / FS4-p	45
10	44	f	r	2	4.4	Otosclerosis	CI522 & CP910 / ACE	55
11	67	f	r	1	6.7	Sudden hearing loss	CI422 & CP810 / ACE	35
12	42	f	r	1	5.3	Sudden hearing loss	HiRes90K & Naida Q90 / HiRes Optima-S	80
13	63	f	l	3	3.7	Sudden hearing loss	FLEX28 & RONDO / FS4-p	55
14	77	f	r	13	2.10	Ménière's / Sudden hearing loss	FLEX28 & SONNET / FS4	30
15	60	m	r	1	3.7	Sudden hearing loss	FLEX28 & RONDO / FS4-p	35
16	78	f	r	1	5.0	Sudden hearing loss	FLEX28 & SONNET / FS4	35
17	70	m	r	1	2.1	Sudden hearing loss	HiRes Ultra & Naida Q90 / HiRes Optima-S	70
18	26	f	r	1	3.4	Meningitis / Temporal bone fracture	FLEX28 & SONNET / FS4	80
19	66	m	r	30	1.4	Sudden hearing loss	FLEX28 & RONDO2 / FS4-p	55
20	58	m	l	20	4.1	Unknown	HiRes90K & Naida Q70 / HiRes Optima-S	90
	Ø = 60 (12)	**f = 14**	**r = 13**	**Ø = 10 (12)**	**Ø = 4.3 (1.7)**	**Sudden hearing loss = 14**	**MED-EL = 13**	**Ø = 54 (19.6)**

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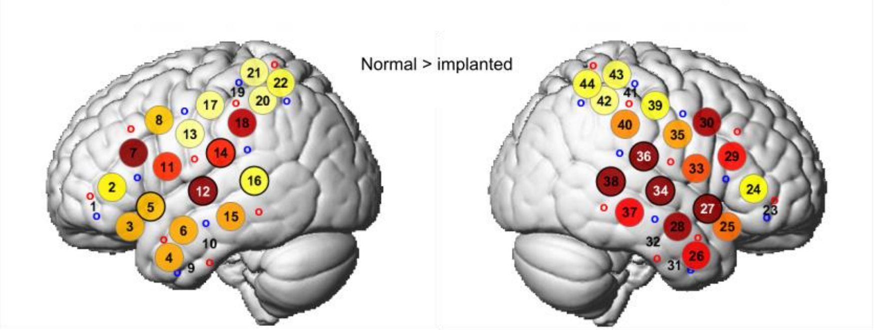
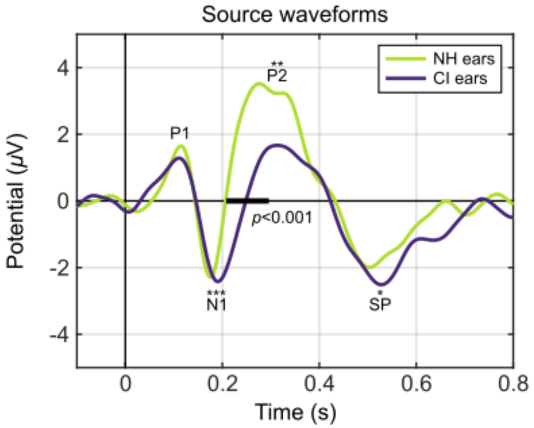
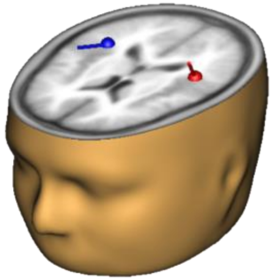
II CI adults







- fNIRS results showed stronger activity along the right STG and near left primary AC for the normal ears

- EEG data showed that P2 was much larger when listening via the normal ears
- Additionally, ERPs peaked significantly later for the CI ears
- P2 dipole source in planum temporale

→P2 has double-peaked morphology, so appears to consist of two subcomponents (Steinmetzger & Rupp, 2024, Imaging Neuroscience, in press)

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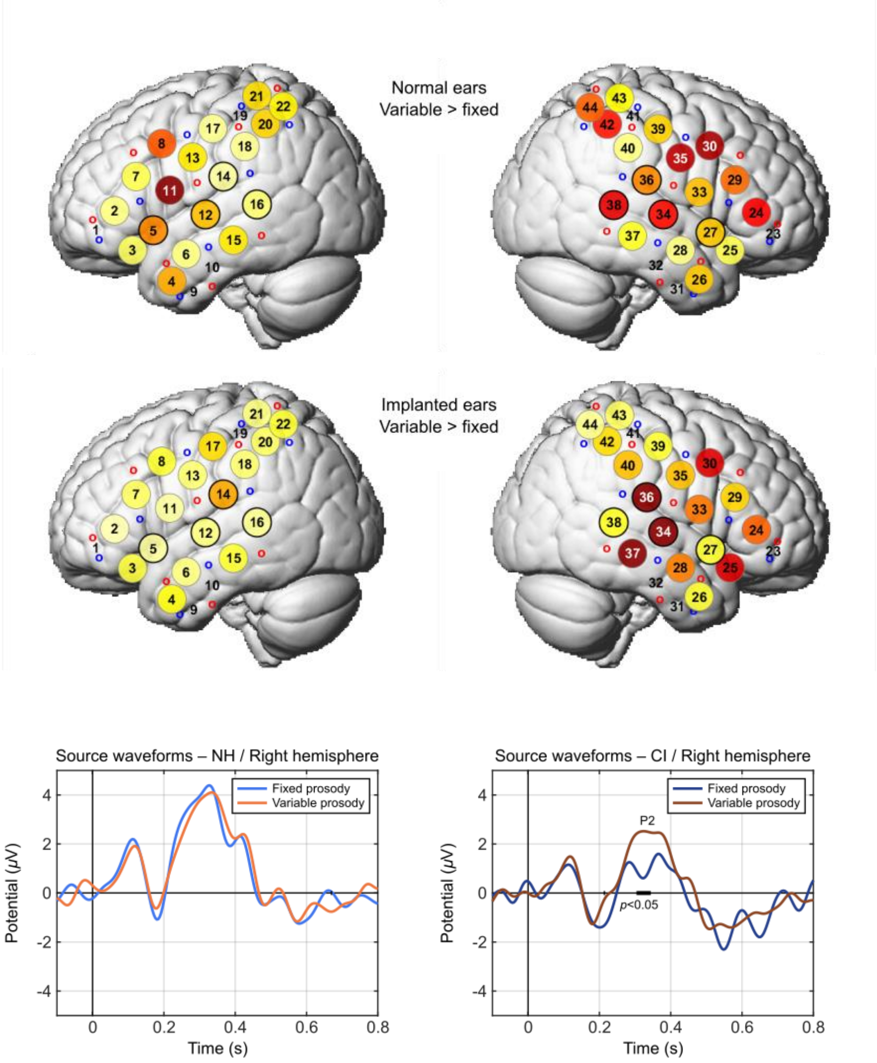
II CI adults



- Surprisingly, neither fNIRS nor EEG results revealed differences between conditions for the normal ears

- However, variable condition led to greater activity for implanted ears – although acoustic difference is much less obvious

→Suggests that saturation of activity levels in the functionally dominant normal ear

Steinmetzger, 2022, NeuroImage: Clinical
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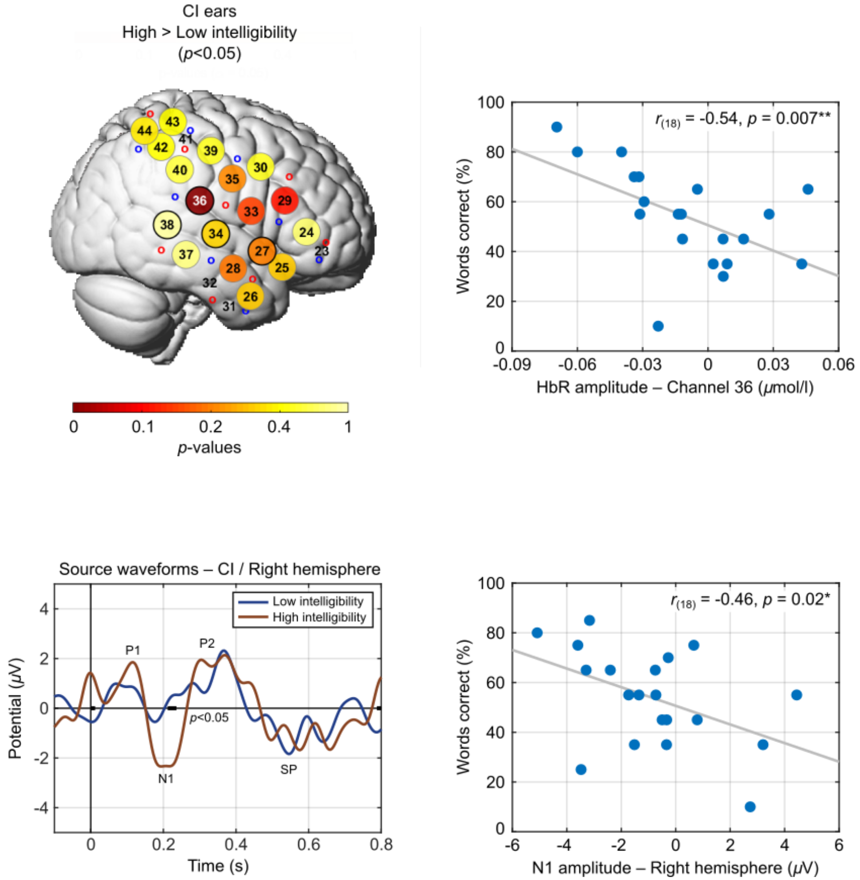
II CI adults



- When listening through the CI ears, fNIRS results also showed that stronger activity in right auditory cortex (channel 36) was associated with better speech intelligibility

- The corresponding EEG data showed that the N1 amplitude in this region was also larger in case of higher speech intelligibility scores

→Demonstrates the that this paradigm may potentially be used for diagnostic purposes

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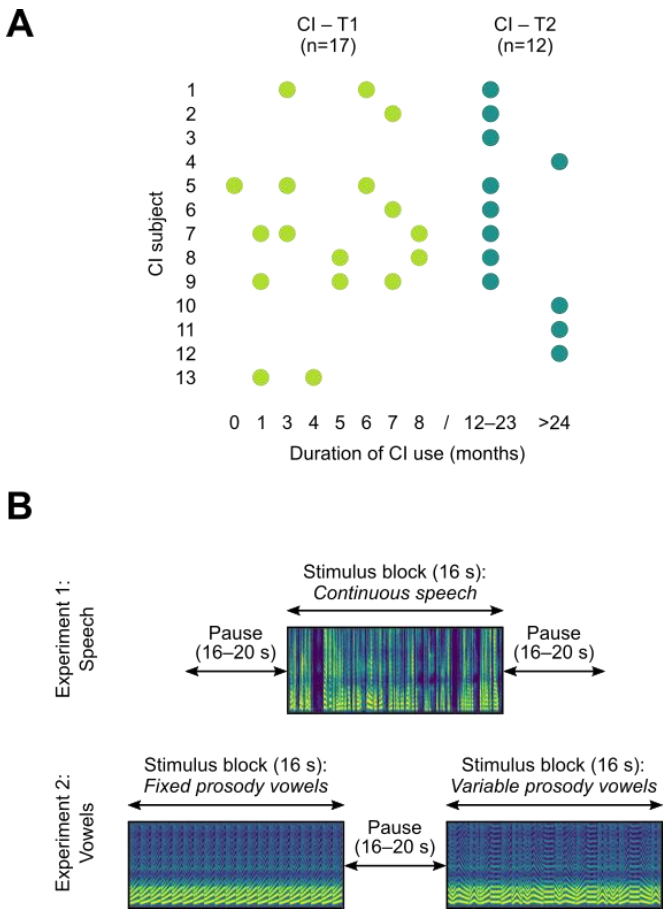
Results: III CI children

III CI children

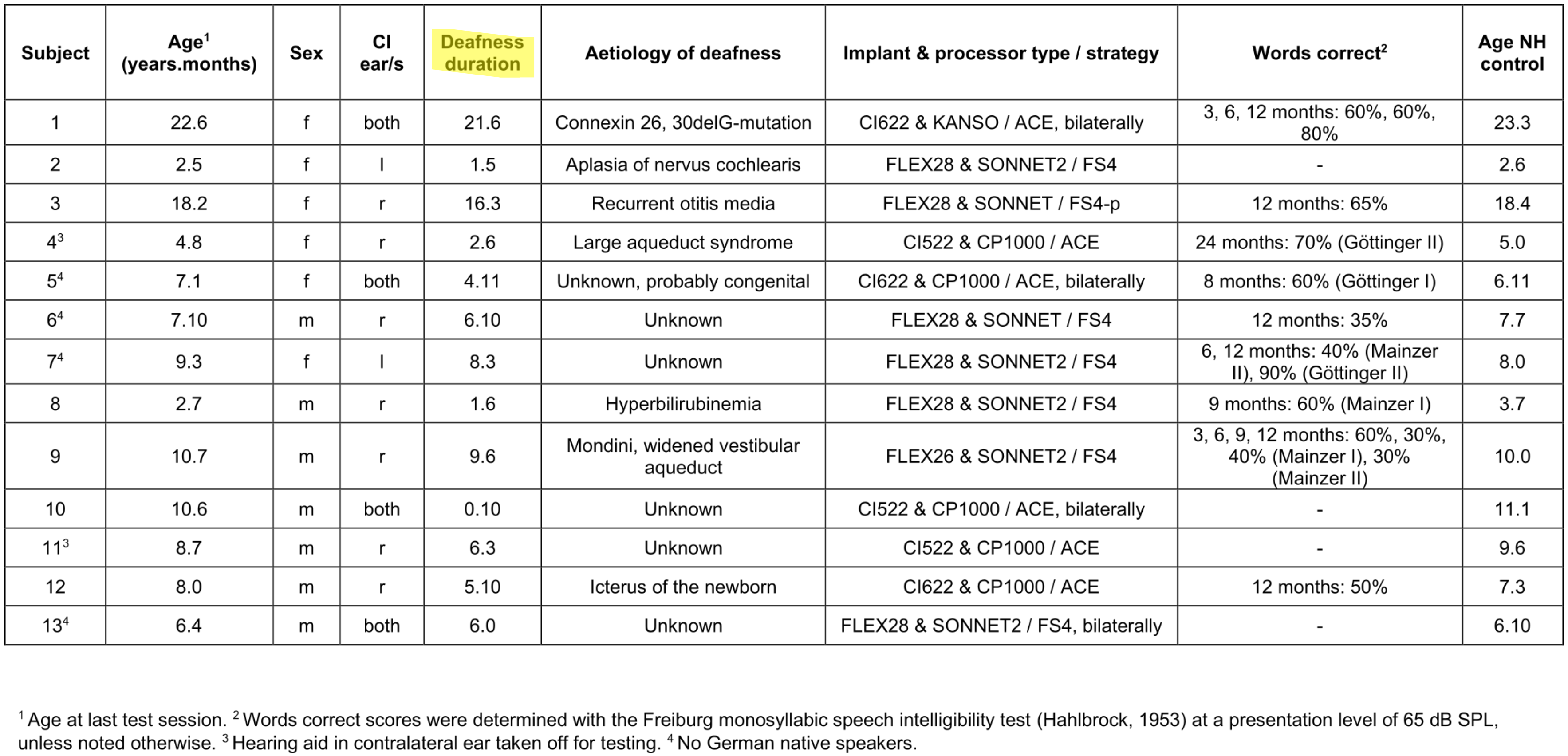


- Groups with *less* (T1) and *more than 1 year* of CI experience (T2), and age-matched control group (NH)
- Mean age ~9 years in all 3 groups
- Children vary widely regarding age, CI configuration, and language background

- Two experiments (speech *and* vowels), with most children in CI – T1 group tested repeatedly

Steinmetzger, 2024, bioRxiv
https://doi.org/10.1101/2024.04.08.588535

II CI children



Subject	Age[1] (years.months)	Sex	CI ear/s	Deafness duration	Aetiology of deafness	Implant & processor type / strategy	Words correct[2]	Age NH control
1	22.6	f	both	21.6	Connexin 26, 30delG-mutation	CI622 & KANSO / ACE, bilaterally	3, 6, 12 months: 60%, 60%, 80%	23.3
2	2.5	f	l	1.5	Aplasia of nervus cochlearis	FLEX28 & SONNET2 / FS4	-	2.6
3	18.2	f	r	16.3	Recurrent otitis media	FLEX28 & SONNET / FS4-p	12 months: 65%	18.4
4[3]	4.8	f	r	2.6	Large aqueduct syndrome	CI522 & CP1000 / ACE	24 months: 70% (Göttinger II)	5.0
5[4]	7.1	f	both	4.11	Unknown, probably congenital	CI622 & CP1000 / ACE, bilaterally	8 months: 60% (Göttinger I)	6.11
6[4]	7.10	m	r	6.10	Unknown	FLEX28 & SONNET / FS4	12 months: 35%	7.7
7[4]	9.3	f	l	8.3	Unknown	FLEX28 & SONNET2 / FS4	6, 12 months: 40% (Mainzer II), 90% (Göttinger II)	8.0
8	2.7	m	r	1.6	Hyperbilirubinemia	FLEX28 & SONNET2 / FS4	9 months: 60% (Mainzer I)	3.7
9	10.7	m	r	9.6	Mondini, widened vestibular aqueduct	FLEX26 & SONNET2 / FS4	3, 6, 9, 12 months: 60%, 30%, 40% (Mainzer I), 30% (Mainzer II)	10.0
10	10.6	m	both	0.10	Unknown	CI522 & CP1000 / ACE, bilaterally	-	11.1
11[3]	8.7	m	r	6.3	Unknown	CI522 & CP1000 / ACE	-	9.6
12	8.0	m	r	5.10	Icterus of the newborn	CI622 & CP1000 / ACE	12 months: 50%	7.3
13[4]	6.4	m	both	6.0	Unknown	FLEX28 & SONNET2 / FS4, bilaterally	-	6.10

[1] Age at last test session. [2] Words correct scores were determined with the Freiburg monosyllabic speech intelligibility test (Hahlbrock, 1953) at a presentation level of 65 dB SPL, unless noted otherwise. [3] Hearing aid in contralateral ear taken off for testing. [4] No German native speakers.

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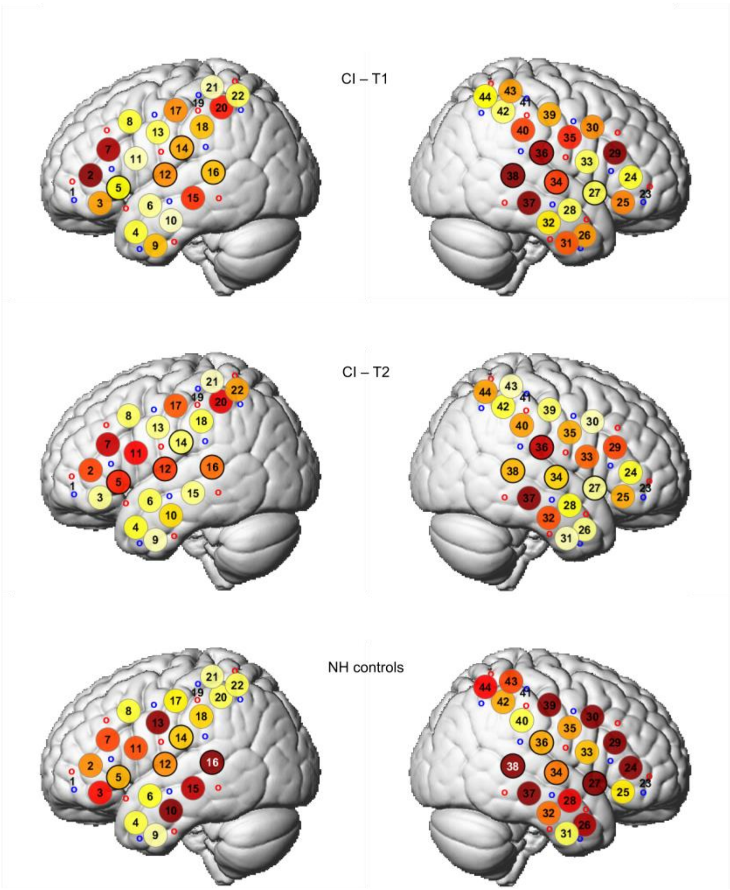
III CI children



- For vowel sequences, both fNIRS and EEG data showed little activity in both CI groups
- Hence, also little difference between CI groups with more and less experience

- For NH control group, bilateral activity near AC and prominent P1

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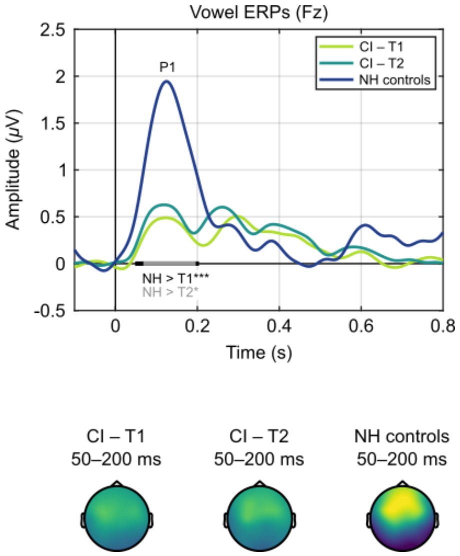

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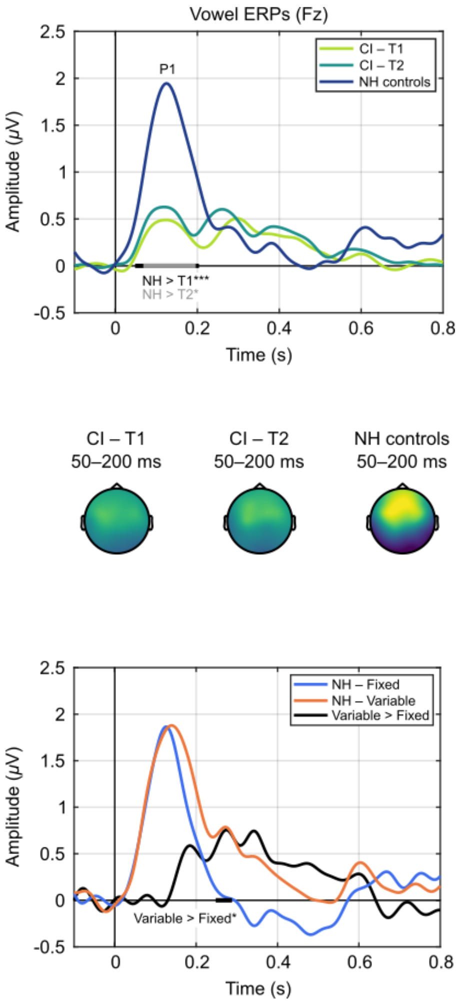

- For vowel sequences, both fNIRS and EEG data showed little activity in both CI groups
- Hence, also little difference between CI groups with more and less experience

- For NH control group, bilateral activity near AC and prominent P1

- Similarly, larger activity in variable prosody conditions only evident for NH controls

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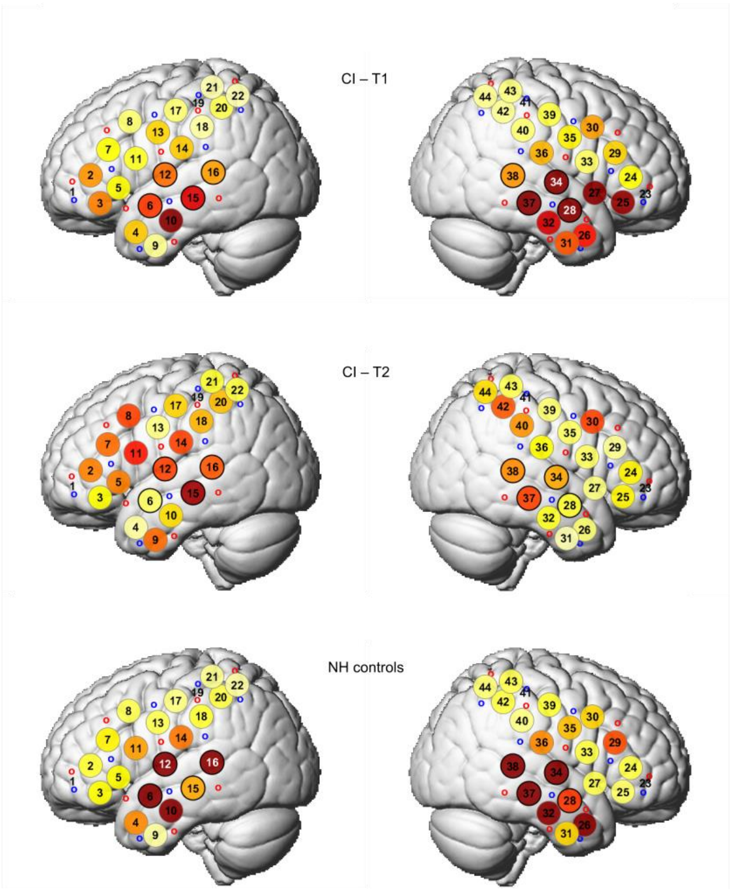
III CI children



- For speech, less experienced CI group showed an abnormal shift of activity to the right hemisphere

- For NH controls, stronger overall activity and slight lateralisation to the left hemisphere

  →Implies that adaptation to CI-based hearing not characterised by increase of activity in left-hemispheric language network, but a reduction of abnormal contralateral activity

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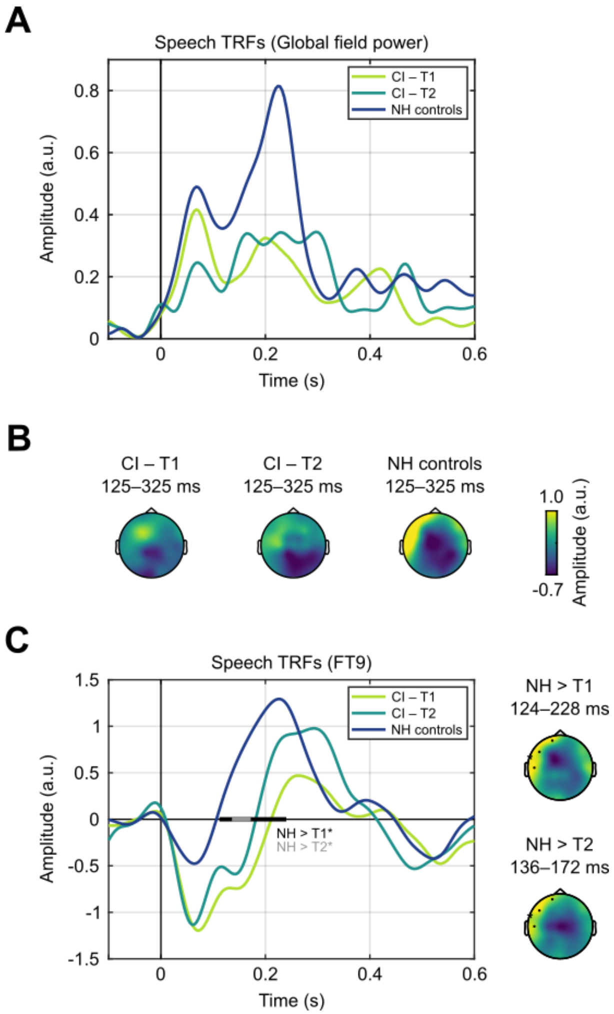
III CI children



- EEG data in response to running speech analysed by modelling envelope-based temporal response functions (TRFs)
- TRFs exhibited prominent positive component (~200 ms) with higher amplitude and shorter latency for NH controls
- Compared to the CI groups, this positive deflection was larger in the NH controls in the left fronto-temporal scalp region
- No significant differences between CI groups, despite trend

Steinmetzger, 2024, bioRxiv
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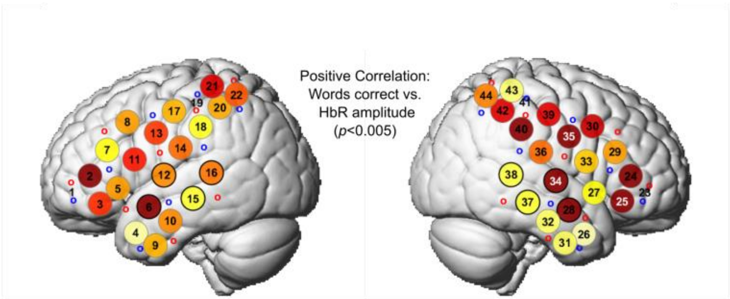
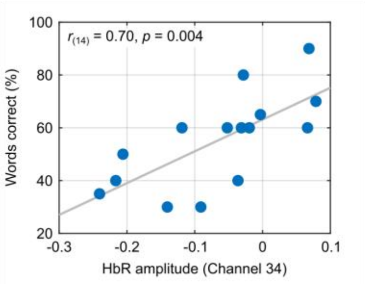
III CI children





- Same as for adult CI users, the fNIRS data reflected the speech intelligibility scores of the paediatric CI users
- In response to running speech, smaller activity in right-hemispheric network coincided with better performance
- Spatial distribution reminiscent of ventral attention network (VAN), whose deactivation is associated with focussed attention

Steinmetzger, 2024, bioRxiv
https://doi.org/10.1101/2024.04.08.588535

3

Summary

Summary

- SSD CI adults:

  →Auditory activity in response to vowels was substantially *smaller and delayed* when listening via the implanted ears, particularly for the P2

  →When listening via the normal ears, large cortical responses in combination with the *absence of a condition difference* suggest an over-activation of auditory cortex

- CI children:

  →Despite trends in this direction, cortical activity *did not increase significantly* with more CI experience and did not approach the higher levels observed in the NH controls

  →However, in the speech experiment, the less experienced CI group showed an abnormal *shift of activity* to the right hemisphere not observed in the other two groups

People involved & funding

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