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Investigating auditory perception in CI users using combined fNIRS-EEG measurements

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Introduction

- Objective assessment of CI-based hearing using combined fNIRS and EEG measurements. Using source-level EEG analyses to validate the fNIRS results
- 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: After the end of the project, the transfer to everyday clinical practice will take place.
- Funded by the Dietmar Hopp Stiftung (2017–): Collaboration between neurology department and ENT clinic

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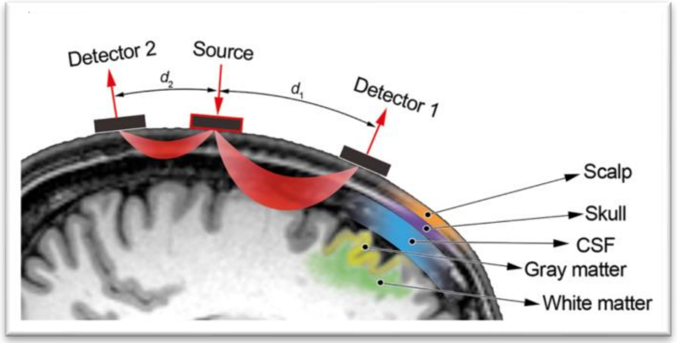
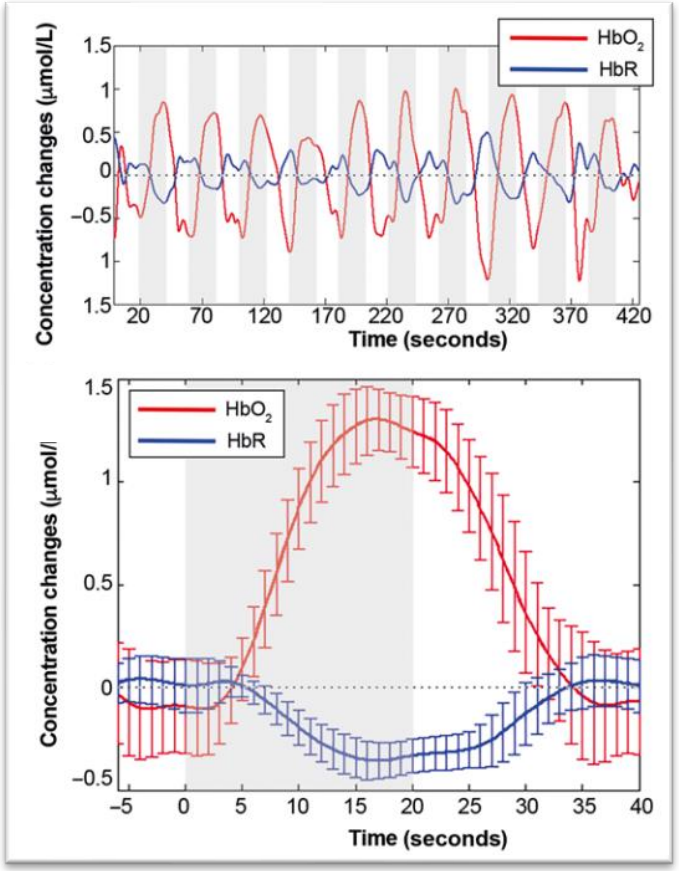
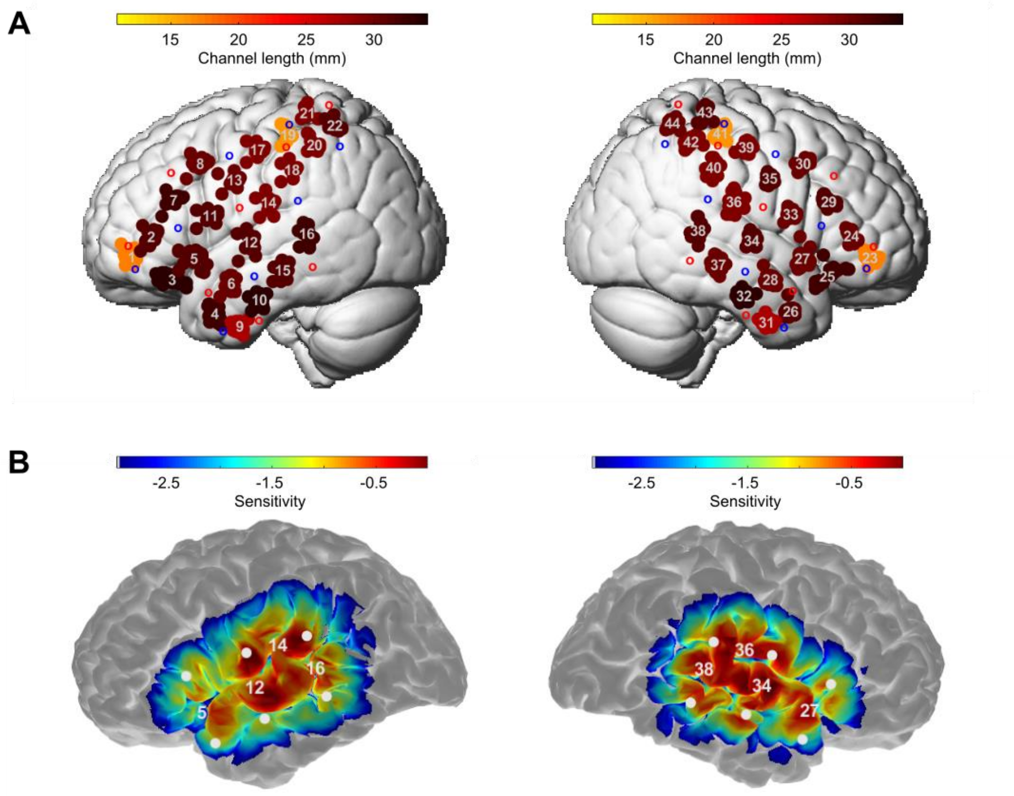
Functional near-infrared spectroscopy (fNIRS)





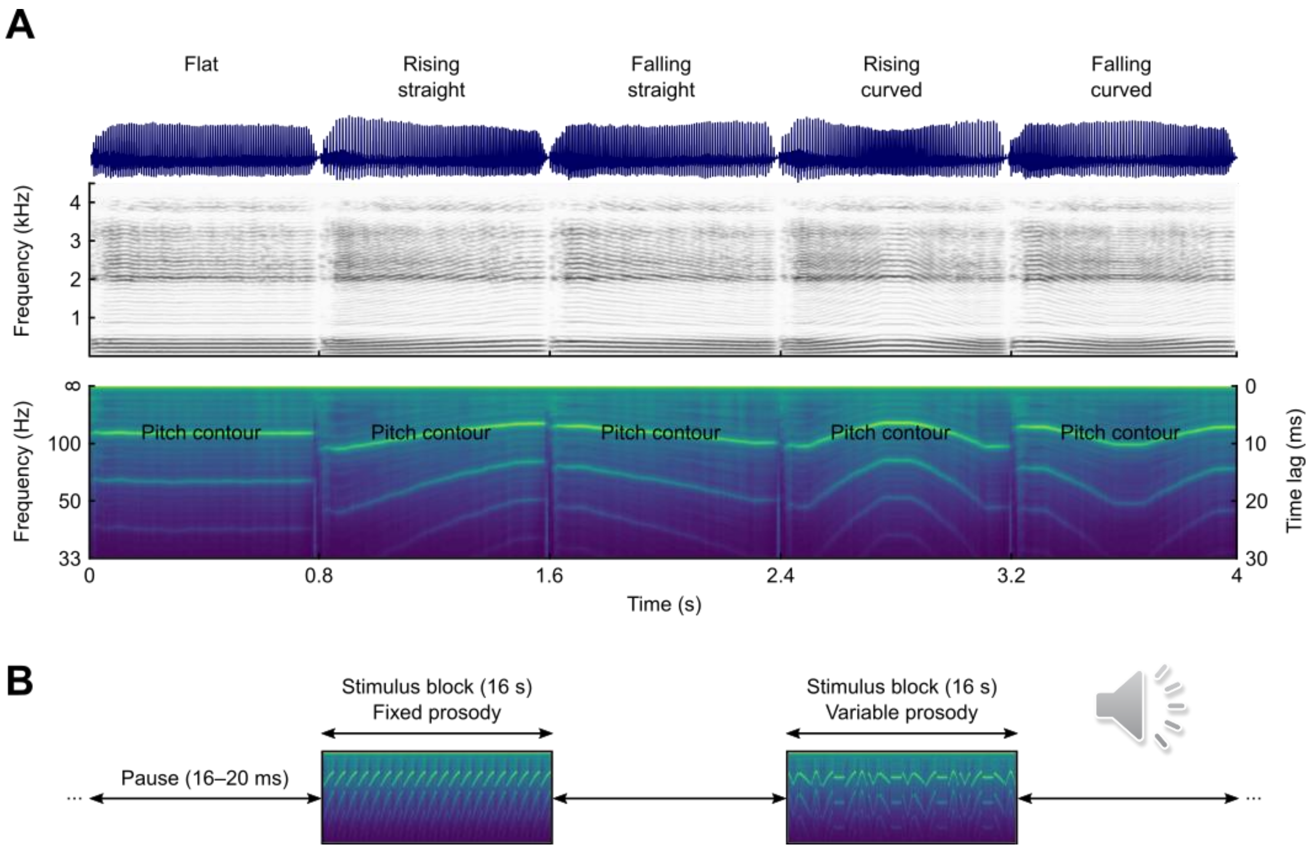
Functional near-infrared spectroscopy (fNIRS)

- fNIRS sensor positions were determined using a 3D localiser. MNI positions of individual subjects show little variability.
- Two short channels per hemisphere to limit the influence of systemic artefacts
- Most analyses were based on two auditory regions of interest (ROIs). These ROIs covered the STGs in both hemispheres, as demonstrated by the sensitivity profiles.



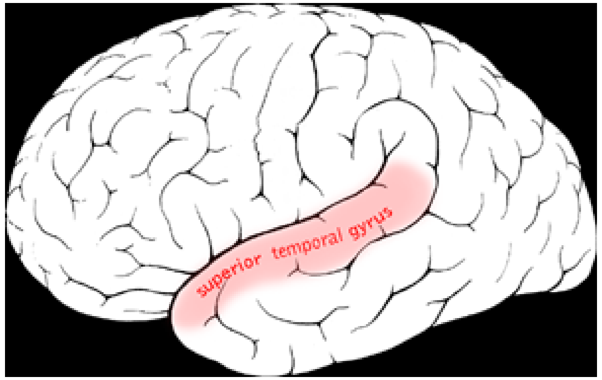
Stimuli: Vowel sequences with prosodic changes

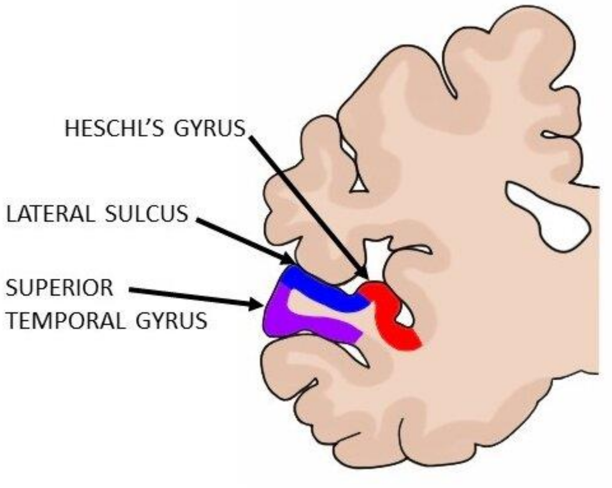
- Natural German vowels were synthesised with five different prosodic contours.
- All other acoustic parameters were controlled using the TANDEM-STRAIGHT vocoder.
- The vowels were used to form *continuous* sequences with fixed or variable prosodic contours.



Experimental paradigm

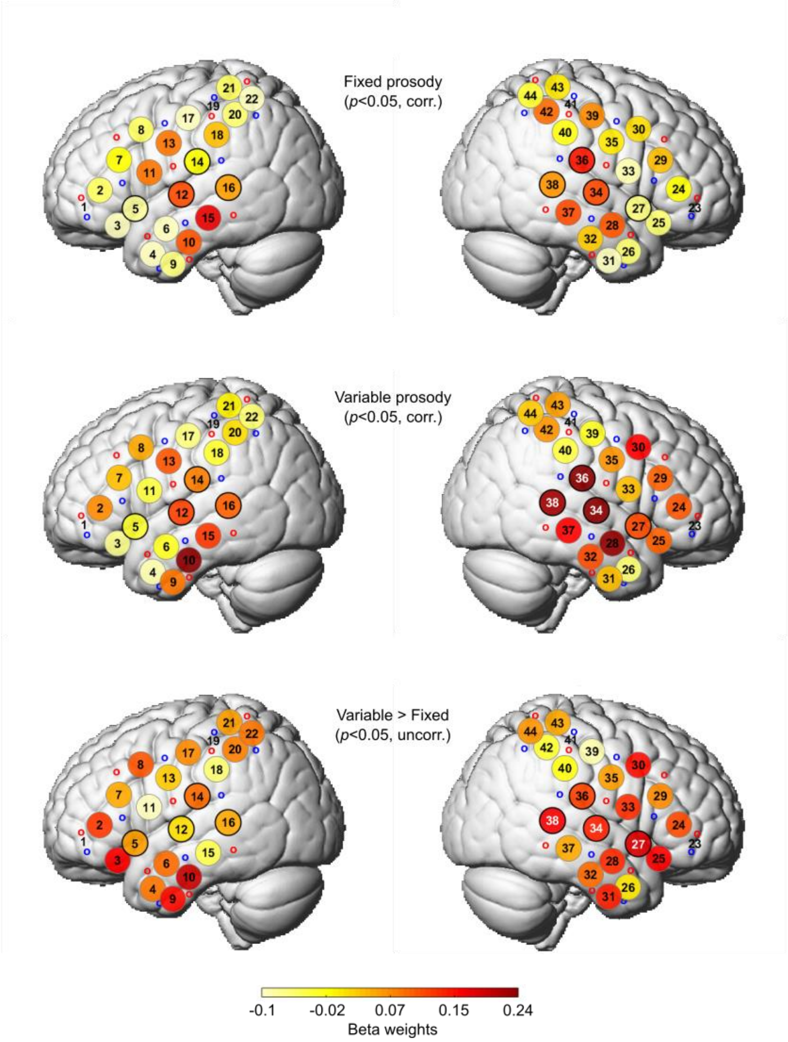
- Commenced project by testing young normal-hearing listeners to obtain a “standard model” of cortical activity
- Unlike secondary areas in superior temporal cortex, deep sources in primary auditory cortex unlikely to be reached with fNIRS
- Difference between fixed and variable conditions is obvious with normal hearing, but at best subtle when listening through CIs
- Pitch changes are processed in anterior portion of right STG, but unclear how prosodic variability is represented and how this is reflected in the ERPs





1. Normal-hearing listeners: fNIRS results

- fNIRS HbO (and HbR) results showed stronger activity along the right STG in the variable prosody condition



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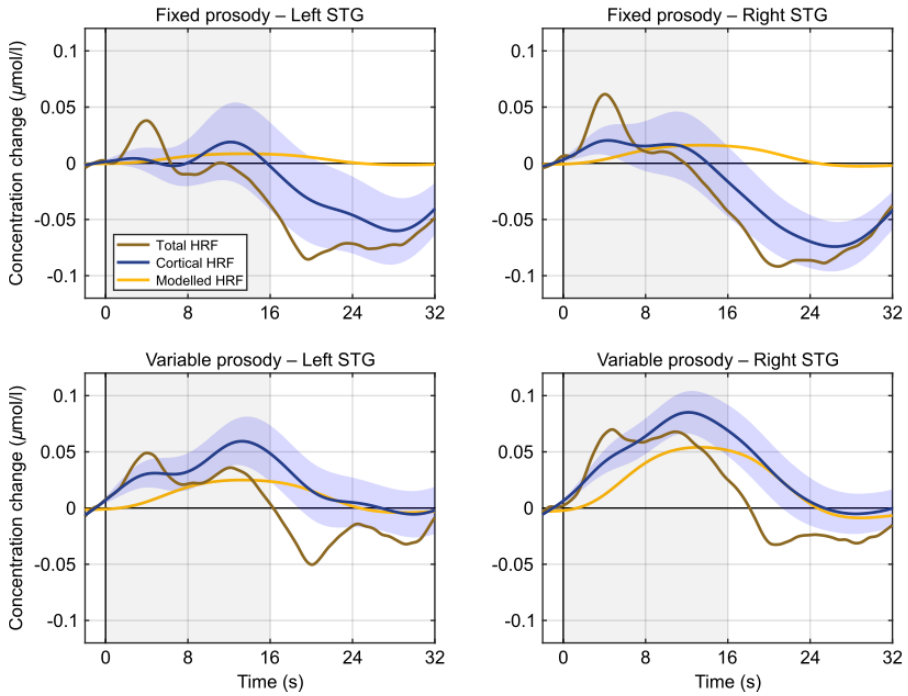

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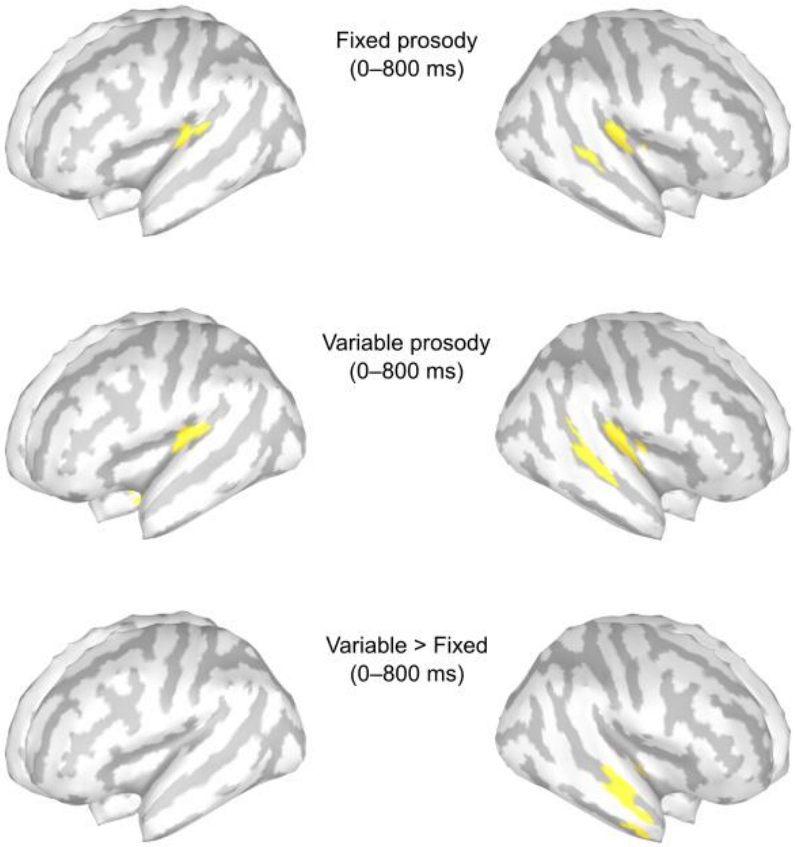
- ERP source localisations showed a similar pattern, with stronger activity along right STS in the variable prosody condition



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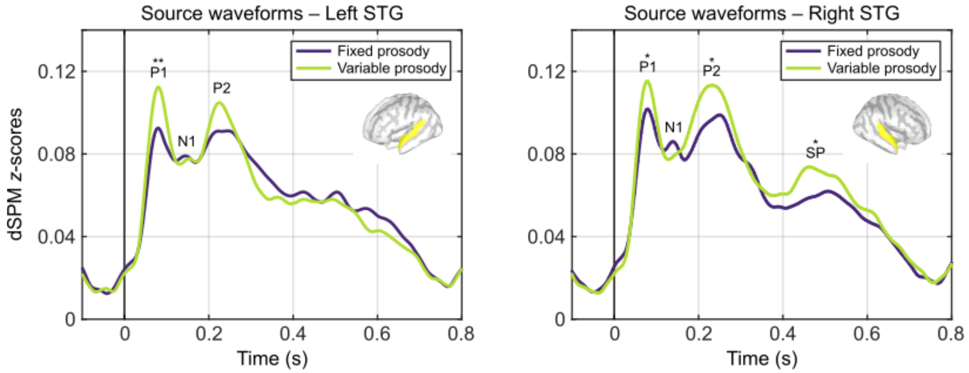
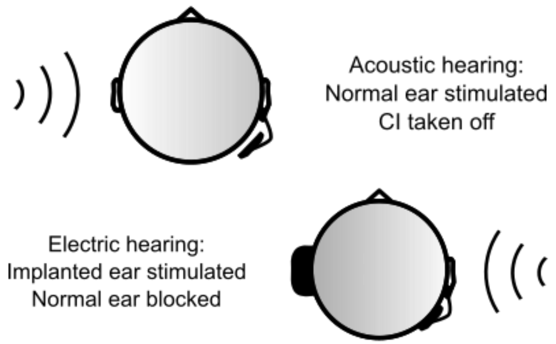
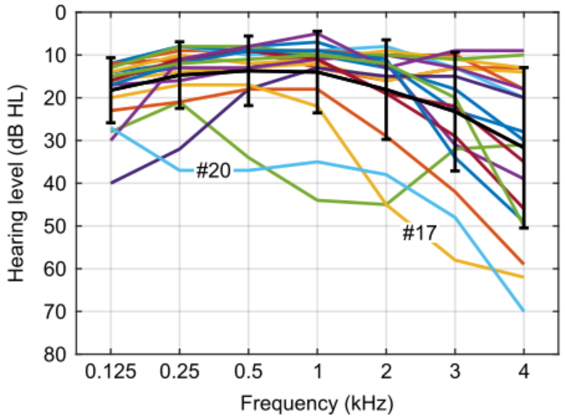
- ERP source localisations showed a similar pattern, with stronger activity along right STS in the variable prosody condition
- Bilateral P1 effect throughout the sequences, but P2 and sustained potential only larger during 2nd half of blocks and in right STG, reflecting adaptation and prediction-related activity.



Experimental paradigm II

- In a second step, we tested 20 unilateral adult CI users with preserved normal hearing in the other ear.
- 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.



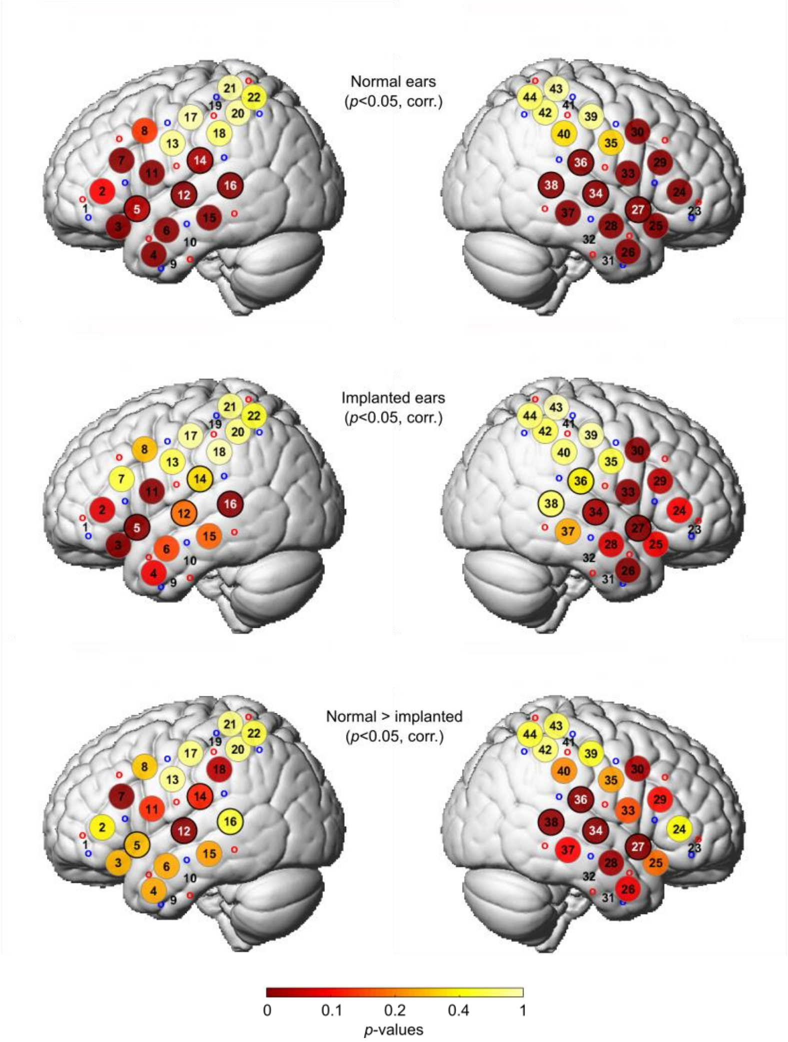


Adult CI users: subject data

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)**

2. Adult CI users: fNIRS results

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



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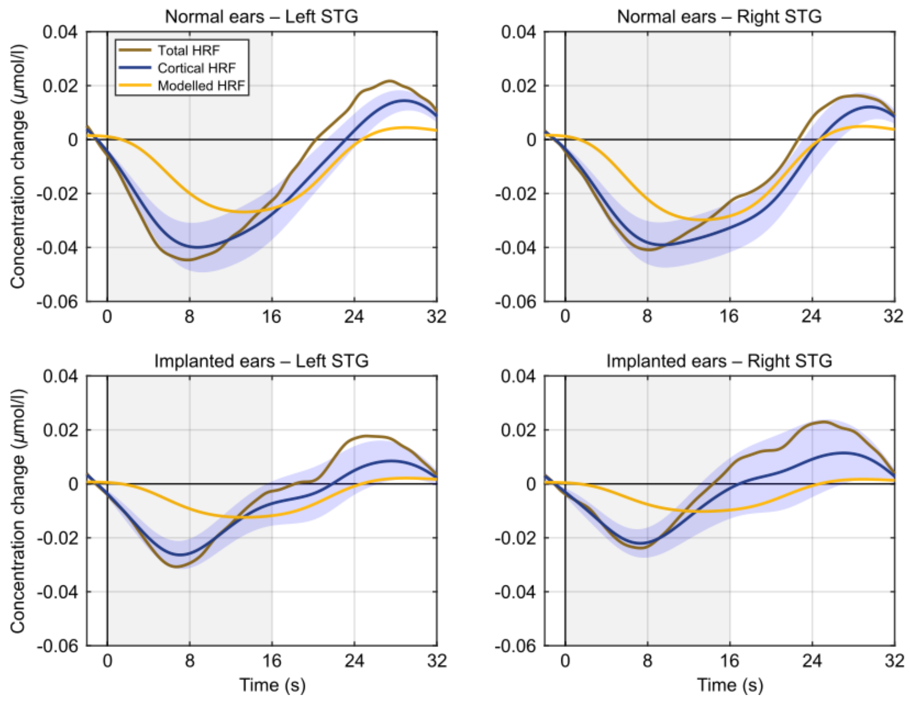

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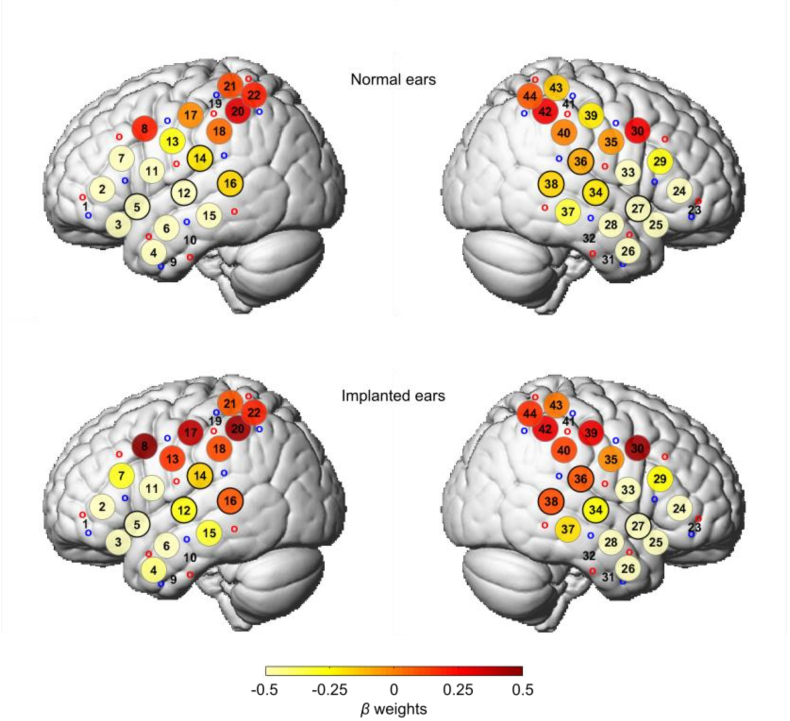
- fNIRS HbO data were dominated by a gradient that masked auditory activity. Effect is discussed at length in a previous paper with normal-hearing listeners (Steinmetzger *et al.*, 2020, HearRes) …
- Gradient appears to reflect increased attention, rather than de-activation of fronto-temporal areas



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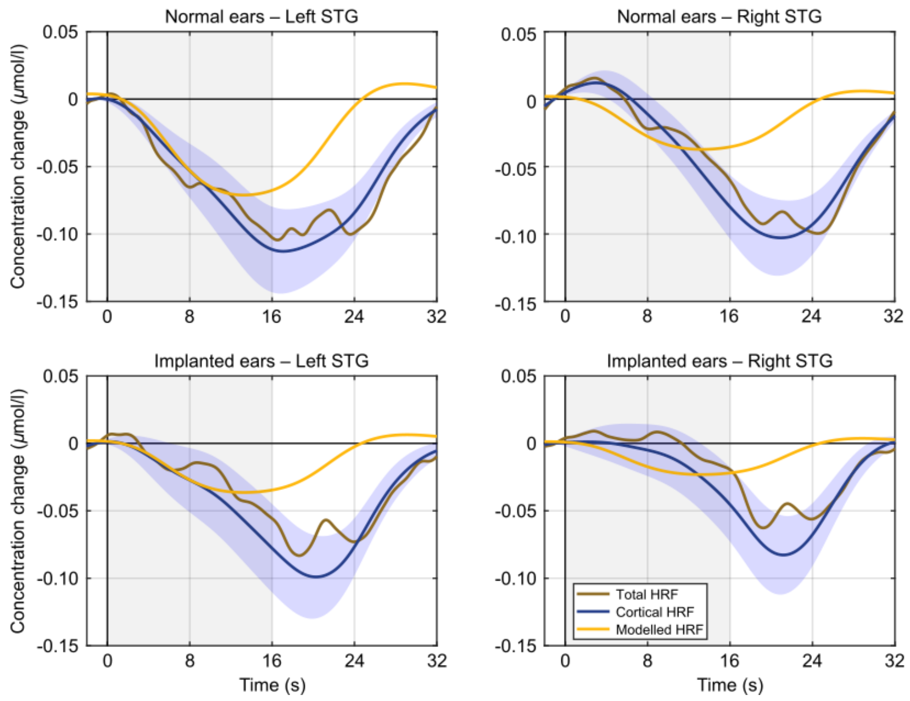
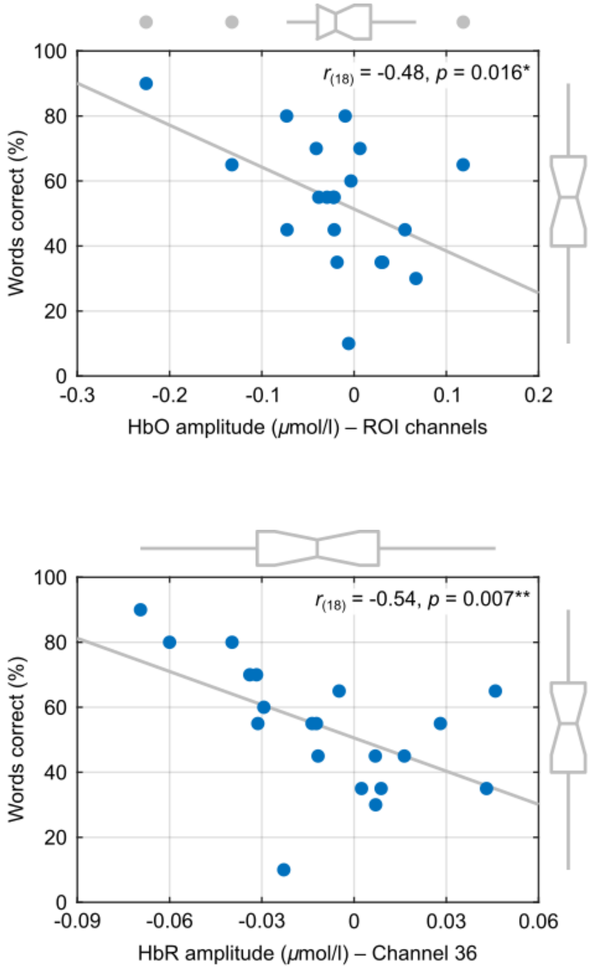


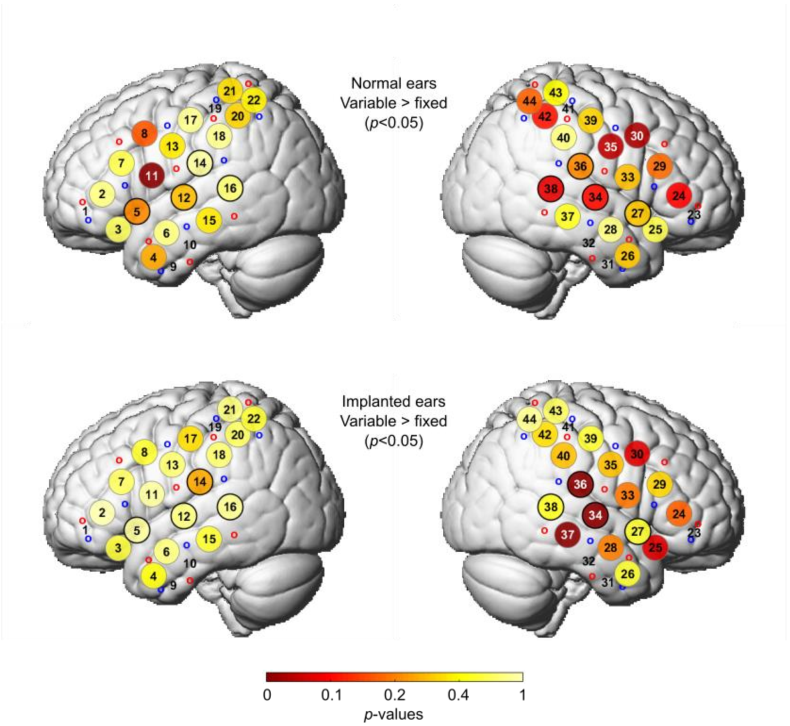
2. Adult CI users: fNIRS results

- The more *negative* the HbO amplitude in auditory areas, the higher the subject's CI speech intelligibility.
- The higher the HbR amplitude near right primary AC, the higher the subject's CI speech intelligibility.



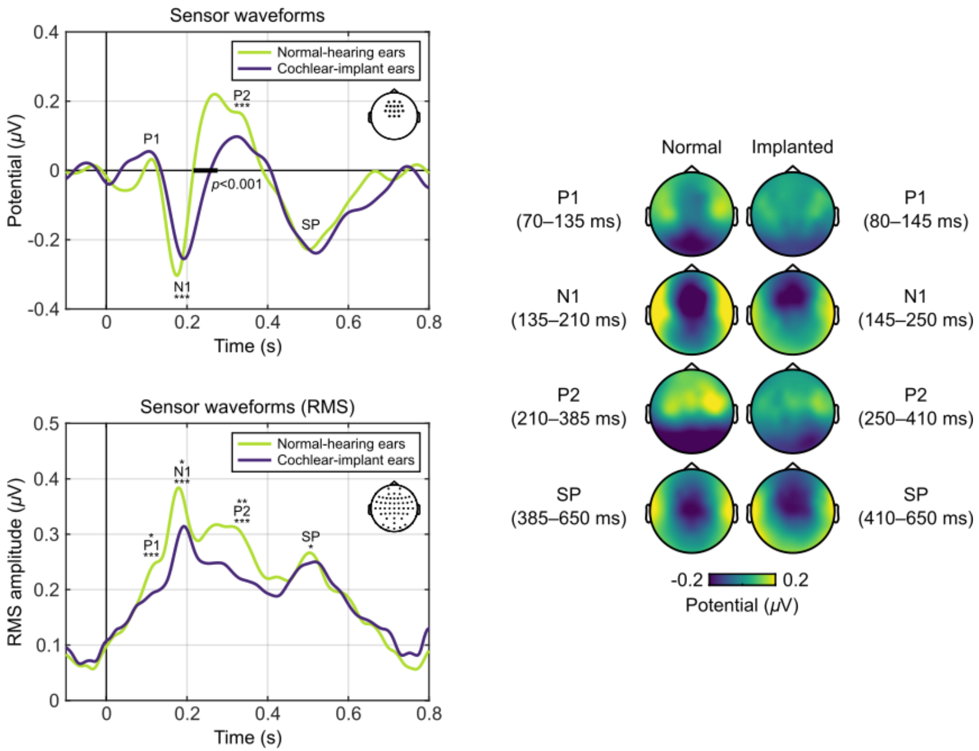
2. Adult CI users: fNIRS results

- fNIRS HbR results revealed no difference between the variable and fixed prosody conditions for the normal ears.
- However, variable condition led to greater activity in right auditory areas for implanted ears – although acoustic difference is much less obvious



2. Adult CI users: EEG results

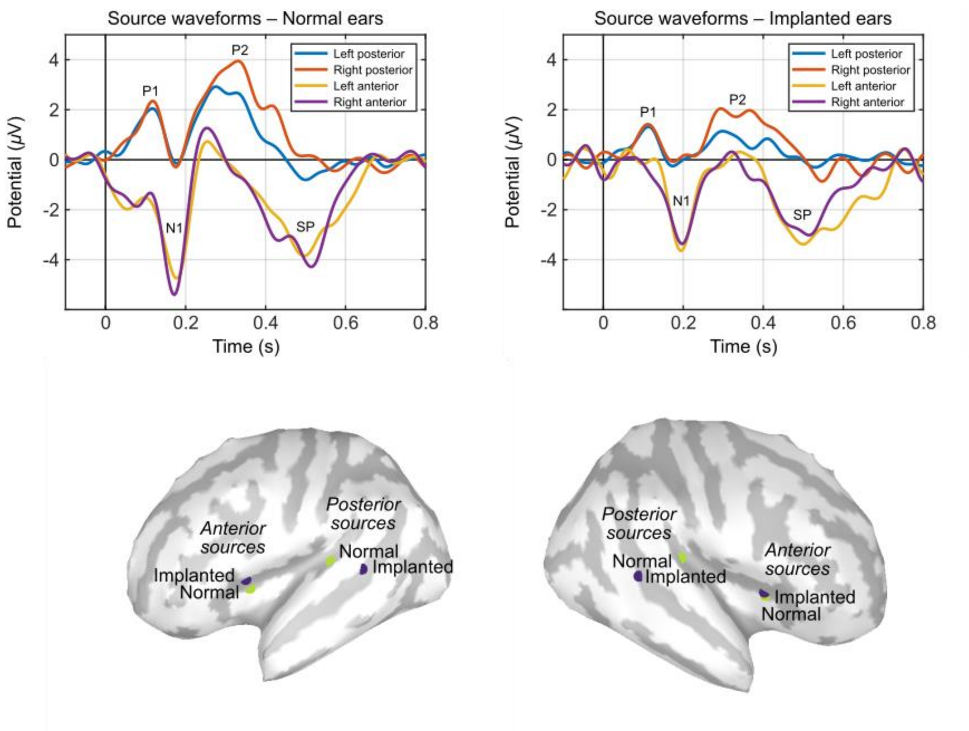
- Sensor-level EEG results also showed larger responses for normal ears, particularly for the P2.
- In addition, the auditory ERPs all peaked significantly later for the implanted ears.
- The scalp distributions were similar across ears.



2. Adult CI users: EEG results

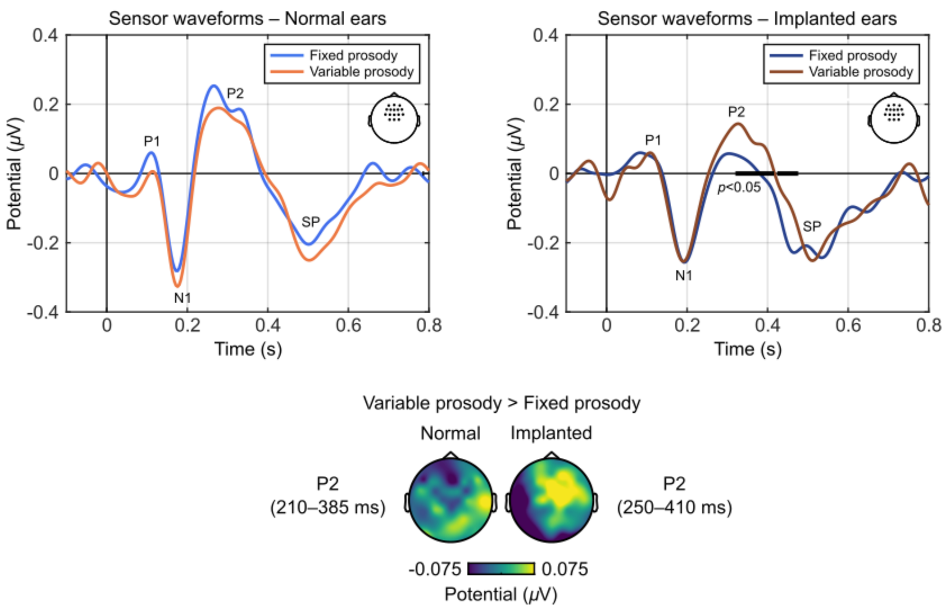
- Dipole source analyses showed that the positive and negative ERP components could be spatially separated

- Dipole locations were similar across ears, suggesting that the same cortical areas were activated when listening with normal and implanted ears



2. Adult CI users: EEG results

- The condition comparison again revealed no difference for the normal ears, but a larger P2 in the variable condition for the implanted ears.



2. Adult CI users: Summary

- Auditory activity was smaller and delayed when listening via the implanted ears.
- Large cortical responses in combination with the absence of a condition difference suggest an over-activation of auditory cortex when listening with the normal ears.
- Both the fNIRS HbO and HbR data were correlated with previously obtained speech intelligibility scores.
- Both the fNIRS *and* EEG data showed few signs of CI artefacts.

Experimental paradigm III

- Currently, we are testing pre-lingually deafened children who have recently received their CIs.
- By testing them several times during the first year after implantation, we hope to track the development of their hearing.
- Using the same passive paradigm as before ensures the comparability with previous data.

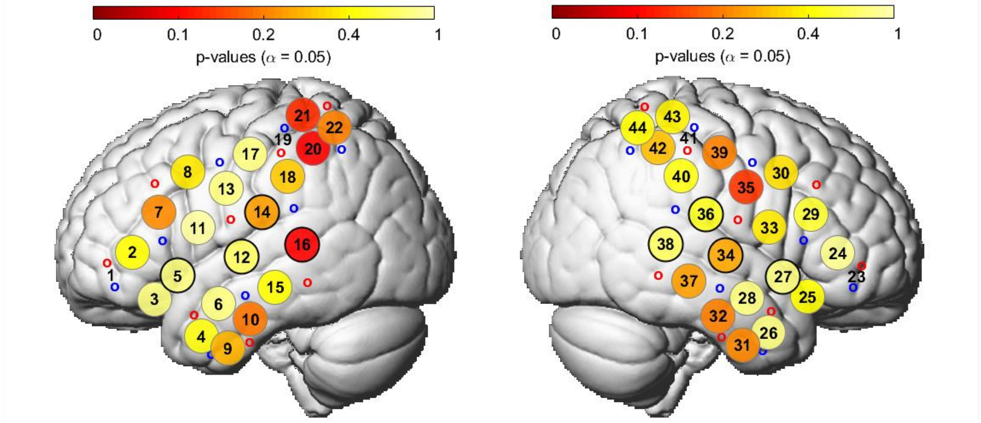
Experimental paradigm III

- The children are recruited via the local ENT clinic and vary widely regarding age, CI configuration, and language background.

- Here, the focus is on the fNIRS data, as the EEG data are heavily affected by artefacts.

3. Cochlear-implant users: Children

- Early after implantation, little auditory cortex activity is evident (mean duration of CI use=2.25 months, n=4, mean age ~9 yrs).



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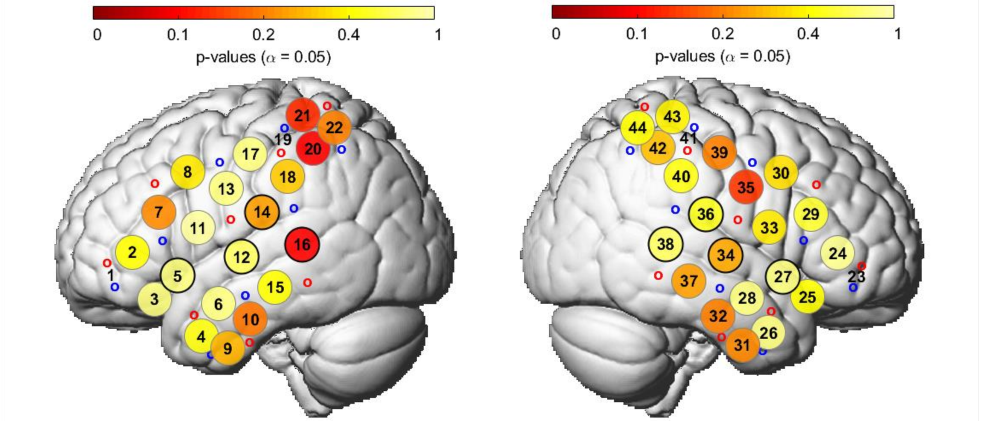
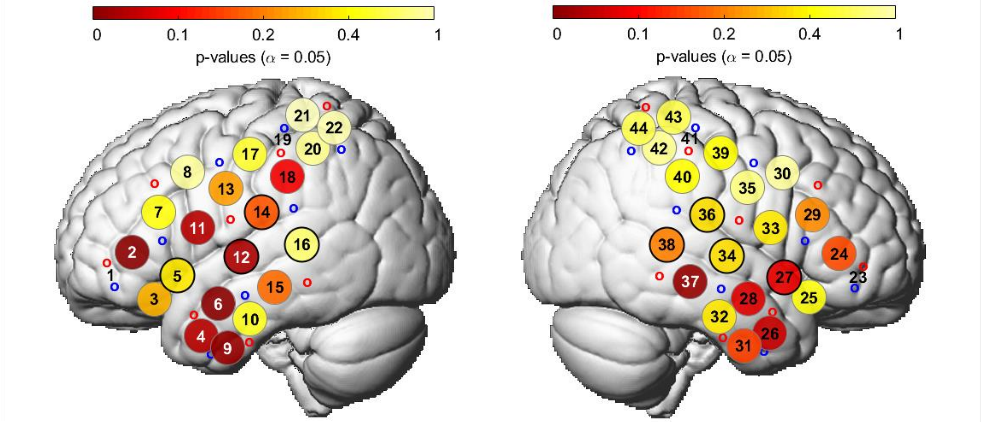
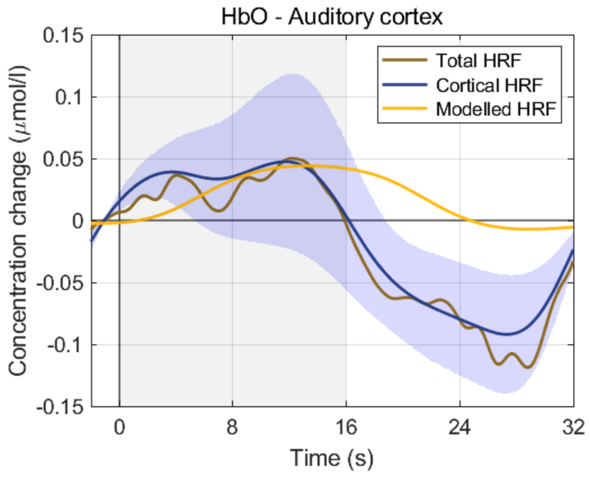


- In contrast, after the first year of CI use, the auditory cortex and neighbouring areas show pronounced activity (mean duration of CI use=12.2 months, n=5, mean age ~11 yrs).



3. Cochlear-implant users: Children

- Similarly, the temporal responses functions recorded from both auditory cortices showed that activity was small early after implantation (2.25 months).



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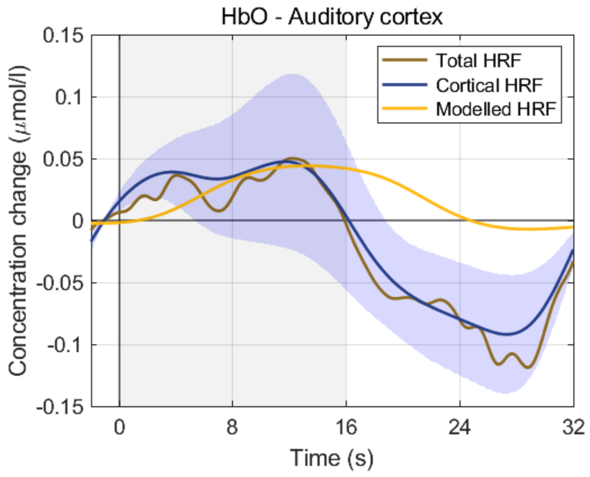
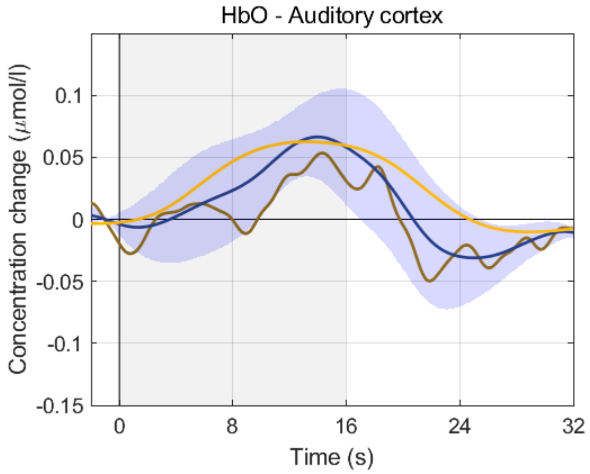


- In contrast, sustained activity and a typical shape of the response functions was evident after the first year of CI use (12.2 months).



Thank you for your attention!

Steinmetzger, K., Megbel, E., Shen, Z., Andermann, M., and Rupp, A. (2020). Cortical activity evoked by voice pitch changes: a combined fNIRS and EEG study. *bioRxiv*, 2020.08.24.264275.

Steinmetzger, K., Shen, Z., Riedel, H., and Rupp, A. (2020). Auditory cortex activity measured with functional near-infrared spectroscopy (fNIRS) appears to be susceptible to masking by cortical blood stealing. *Hearing Research 396*, 108069.