Contributions of low frequency acoustic hearing to binaural sensitivity and speech unmasking in individuals with electric-acoustic stimulation and normal hearing

Binaural Hearing and Speech Laboratory

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Introduction

There is a rapidly growing population of cochlear implant (CI) recipients with acoustic hearing preservation in the implanted ear(s), affording the opportunity to combine electric hearing in one or both ears. Adults with electro-acoustic stimulation (EAS) demonstrate significant benefits for speech understanding in noise and spatial hearing tasks as compared to bimodal hearing [1, 2] who use a hearing aid in one ear and a CI in the other.

The potential of EAS to improve outcomes through added binaural low-frequency acoustic input remains poorly understood. Existing data are highly variable, making it difficult for clinicians to predict the expected benefits of EAS for spatial hearing and real-world listening. This variability may stem from studies involving individuals with significant or asymmetrical hearing loss[3] which is common after implantation. One hypothesized source of variance is the ability to use interaural time and level differences (ITDs and ILDs) conveyed by residual acoustic hearing.

Few data exist on maturation of low-frequency binaural hearing in children with typical hearing (i.e., normal hearing), or the ability to harness binaural hearing for functional benefits such as segregation of speech from noise.

This investigation focuses on the developmental trajectory of low-frequency acoustic hearing in individuals with typical hearing, and in children and adults with EAS, who are tested prior to and following cochlear implantation.

Aims and Questions

- How does binaural sensitivity to ITD and ILD cues develop in children with typical hearing?
- How does this sensitivity emerge in pediatric EAS users following chronic EAS use with bilateral low-frequency acoustic amplification?
- How does binaural sensitivity relate to functional use of binaural cues, such as improvement of speech intelligibility in background noise when binaural cues are available?

These questions are compared in groups of individuals with typical hearing and EAS users

Method

Participants

A total of 33 children (ages 5 to 17, 16 males and 17 females) participated in the study, including 8 with hearing loss who used EAS technology. In addition, 33 adults (ages 18 and older, 13 males and 20 females) took part, 11 of whom had hearing loss. All participants with hearing loss, except for one child, were tested in the following experiment prior to receiving CIs.

Binaural sensitivity thresholds

Stimuli

- 250 Hz pure tone stimuli were used, with a duration of 500 ms, and 20-millisecond $\cos^2$ rise/fall time.
- Each trial consisted of three tones intervals, with an interstimulus interval (ISI) of 750 ms.
- The first tone, referred to as the reference interval, was presented diotically (ITD = 0 µs; ILD = 0 dB).
- Participant could select either the second or third tone which had a non-zero binaural cue.

Procedure

A three-interval, two-alternative forced choice task was implemented with adaptive tracking with a two-down, one-up rule to approximate thresholds as 70.7% on psychometric function. The stimuli were delivered through RadioEar IP30 insert earphones.

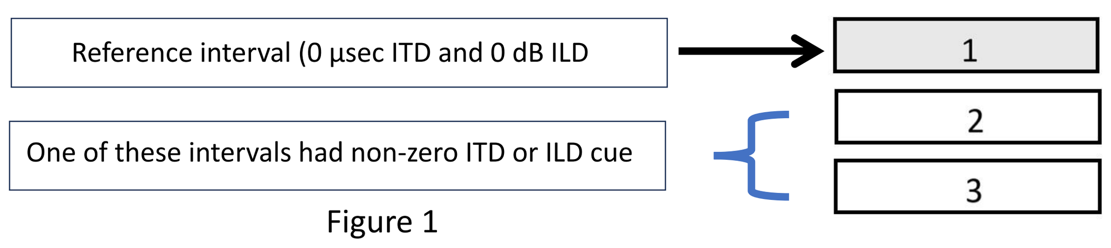

Figure 1

- The step size for adjusting ITD values across trials as follows: a log factor of 0.5 was applied for the first two reversals, 0.2 for the next two, and 0.05 for the remaining trials.
- For the ILD condition, the ILD values were adjusted by 2 dB for the first two reversals, 0.5 dB for the next two, and 0.1 dB for the remaining trials.
- The last eight reversals were averaged to calculate the threshold or just-noticeable difference (JND) for both ITD and ILD tests.

Binaural Intelligibility Level Difference (BILD)

In the present study, BILD is defined as the difference in speech reception thresholds (SRT) in homophasic (N0) noise between two conditions: in one condition, spondees were homophasic (S_0) and in another condition, spondees were antiphasic (S_π) in across the two ears (S_π). This difference demonstrated a functional benefit of binaural hearing.

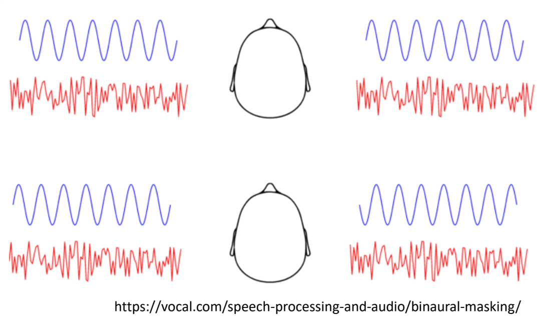

Figure 2

Stimuli

- Signals were spondiac words uttered by a male talker and presented at varying signal-to-noise ratios (SNRs) [from 20 to -60 dB.] Noise was broadband, Gaussian speech-shaped noise at 70 dB SPL.
- The intensity of the noise remained constant at 70 dB SPL, while the intensity of the spondees was adjusted to create the required SNR.

Procedure

In each condition, the SRT in noise was determined by adjusting the signal-to-noise ratio (SNR) adaptively in a 1-up, 1-down procedure until 50% of the target words were repeated correctly. The stimuli were delivered through insert earphones.
The test began with a step size of 5 dB, and after two reversals, the step size decreased to 1 dB. The threshold was determined based on the last six reversals for each condition in each run. Each condition was repeated three times.

Results

ITD and ILD thresholds

ITD and ILD thresholds are shown for children and adults with typical hearing and hearing loss. Substantial variability was observed within each group.

	Typical Hearing		Hearing Loss	
	Children	Adults	Children	Adults
ITD (µsec)	303±49	231±36	1112±159	821±159
ILD (dB)	5.06±0.6	3.7±0.6	12.1±0.2	3.6±0.8

Mean and standard error of ITD and ILD thresholds by group and hearing status

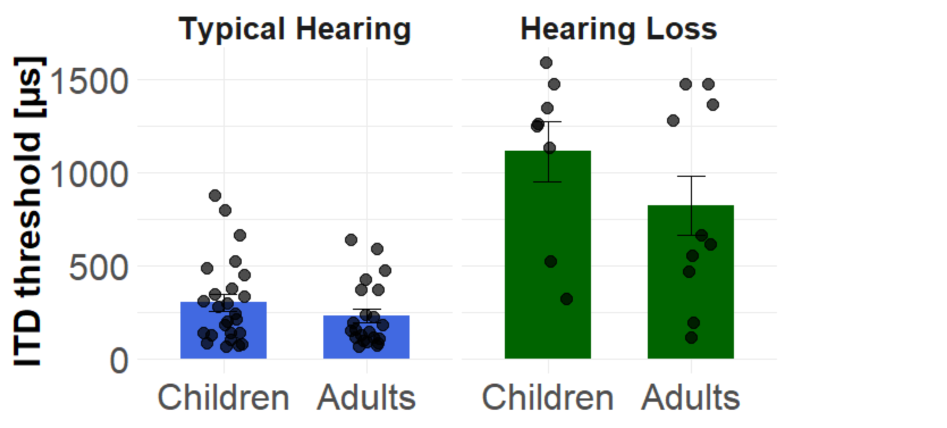

Figure 3: ITD thresholds across age groups and hearing statuses

In the ITD condition, typical hearing children and adults showed substantially lower thresholds than the counterparts with hearing loss, many who had thresholds above the physiologically relevant range of ~750 µs.

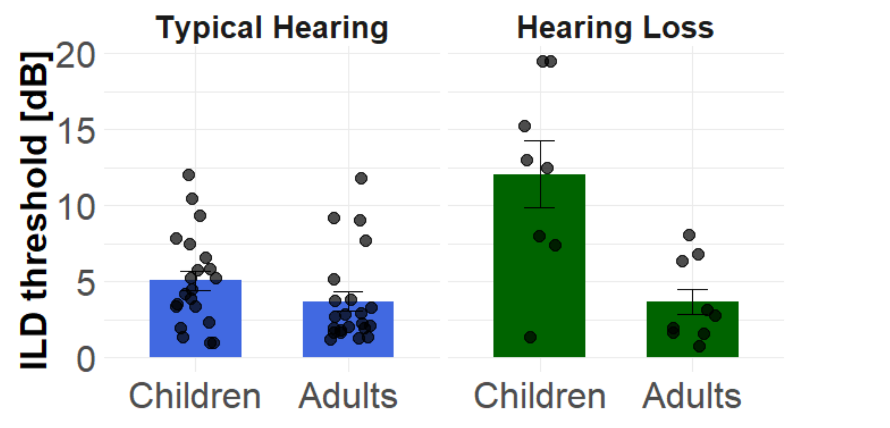

Figure 4: ILD thresholds across age groups and hearing statuses

In the ILD conditions, while thresholds were lower in the typical hearing groups, adults with hearing loss showed performance in the range of typical hearing listeners.

Binaural sensitivity and age

Age and ITD

Predictor	t value	p-value
Intercept	4.094	0.0003
Age	-2.61	0.0139
Hearing Status	6.5	<0.0001

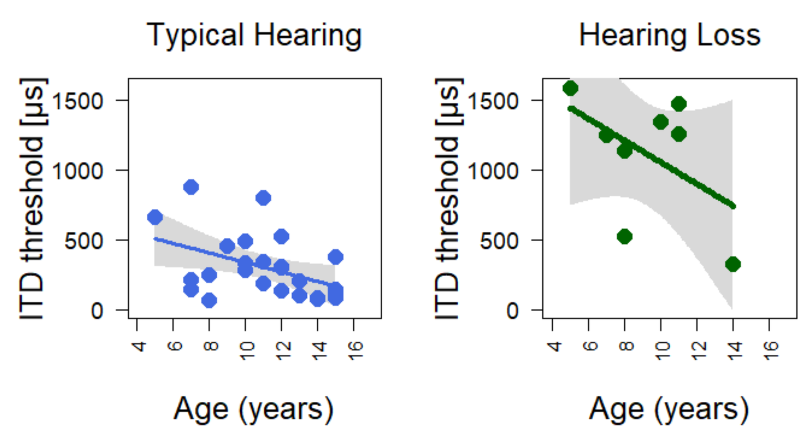

Figure 5: ITD thresholds over age range

An increase in age was associated with a decrease in ITD thresholds, indicating improved sensitivity. Additionally, children with hearing loss exhibited significantly poorer ITD sensitivity compared to their peers with typical hearing.

Age and ILD

Predictor	t value	p-value
Intercept	3.103	0.0046
Age	-1.73	0.095
Hearing Status	3.28	0.003

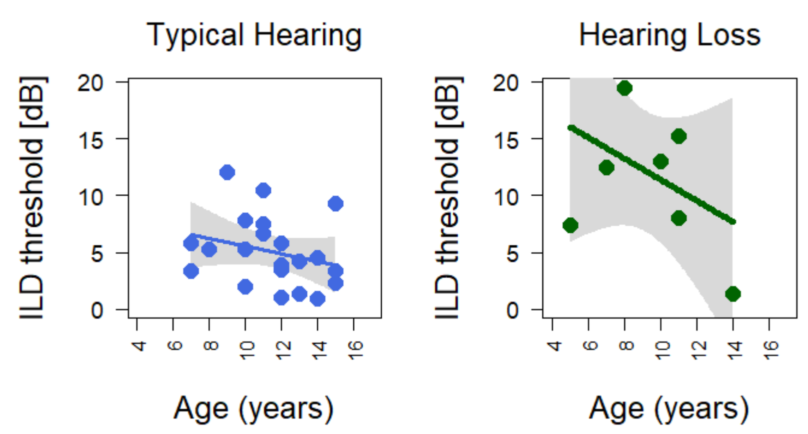

Figure 6: ILD thresholds over age range

Children with hearing loss had significantly higher ILD thresholds compared to those with typical hearing

ILD versus ITD

ITD and ILD were strongly correlated in both groups, with stronger associations seen among children with hearing loss.

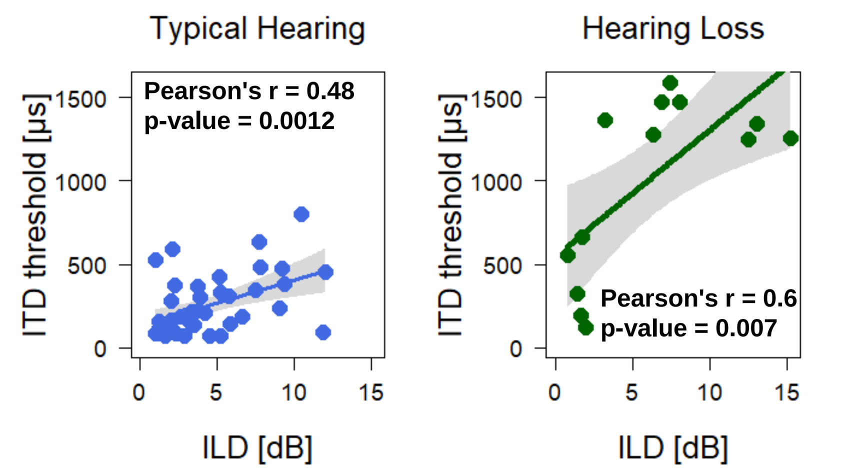

Figure 9: The relationship between ITD and ILD across different hearing status groups

Binaural thresholds versus BILD

ITD versus BILD

Predictor	t-value	p-value
Intercept	15.718	<0.001
ITD (µs)	-2.032	0.051
Hearing Status	-0.083	0.935

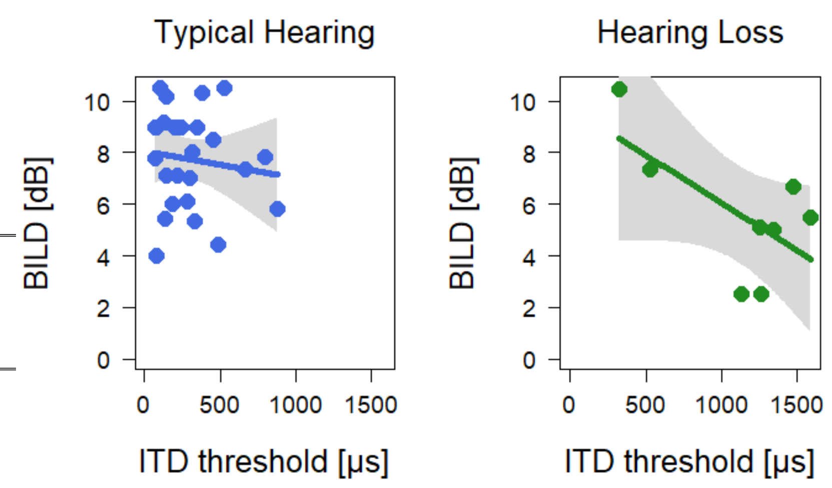

Figure 7: association between ITD and BILD

ITD accounted for the largest proportion of variance in the model, with a trend suggesting that better ITD sensitivity was associated with enhanced BILD performance. In contrast, hearing status was not a significant predictor of BILD.

ILD versus BILD

Predictor	t-value	p-value
Intercept	12.721	<0.001
ILD (dB)	-1.651	0.111
Hearing Status	-0.872	0.391

In the model, neither ILD nor Hearing Status was significantly associated with BILD

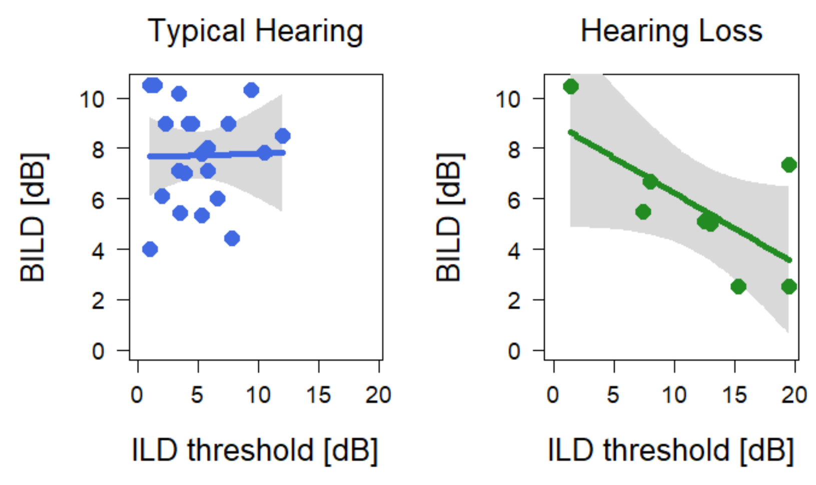

Figure 8: association between ILD and BILD

Summary and Conclusion

These findings indicate that spatial hearing abilities, ITD and ILD sensitivity are adversely affected by hearing loss, with ITD showing increased sensitivity to both age and hearing status. This pattern suggests that the development of ITD sensitivity may require a longer maturation period, particularly in children with hearing loss, pointing to a delay in binaural temporal processing.

Moreover, the results support the idea that binaural temporal and level cues are interrelated and jointly vulnerable to degradation from hearing impairment. This interconnection highlights the broader and more systemic impact of hearing loss on spatial auditory processing.

Notably, individual differences in spatial cue processing, rather than hearing status alone, appear to be stronger predictors of BILD performance. While hearing status did not significantly predict BILD, ITD sensitivity did—underscoring that successful speech-in-noise detection relies on more than temporal coding alone. These findings reinforce the importance of preserving or rehabilitating spatial cue sensitivity in clinical populations.

The relatively small sample size of children with hearing loss limits statistical power and the ability to generalize group differences. A larger and more balanced sample is needed to draw more definitive conclusions about developmental trajectories and the mechanisms underlying binaural processing in children with hearing loss.

Finally, binaural sensitivity in children is likely shaped not only by sensory input but also by non-sensory factors such as attention and indecision. Prior research has demonstrated that performance on lateralization tasks may be influenced by attentional lapses[4], especially under conditions of increased task difficulty. Such difficulty may arise from younger age, hearing loss, or inherent task demands. Consequently, the next step in analyzing these data should involve incorporating metrics that account for non-sensory influences, such as lapse rate, which may have affected performance during the experiments.

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