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ABSTRACT

Background

Motivated by the fact that bilaterally implanted children show significantly worse sound localization skills than their normal hearing (NH) peers, we investigate whether this can be attributed to poor binaural sensitivity, or other factors. When locating sounds, NH listeners use interaural timing differences (ITDs), and interaural level differences (ILDs) in the low-frequency fine structure and high frequency envelopes. The challenge when comparing NH and CI listeners is to use comparably degraded binaural cues. This study is the first to systematically test binaural sensitivity in NH children using CI simulations, and to demonstrate that binaural sensitivity is task-dependent.

Methods

Eleven NH children (ages 8-10) participated in two experiments. In Experiment 1, intra-cranial lateralization was measured for three stimuli: (1) Spondaic words, (2) Transposed tones (4 kHz carrier modulated at 125 Hz), and (3) 500 ms Gaussian-enveloped tone (GET) pulse train (4 kHz center frequency, 100 pulses per second). ITDs (0, ±50, ±100, ±200, ±400, and ±800µs) and ILDs (0, ±1.5, ±3, ±6, ±9, and ±15dB) were imposed on the stimuli and tested in separate blocks of trials. Prior to beginning Experiment 1, children were trained on the task for each set of stimuli. In Experiment 2, just noticeable differences (JNDs) were measured for the transposed tone and GET.

Results

When using binaurally degraded stimuli, preliminary results show children have JNDs ranging from ~10-70 µs for ITDs, and ~0.5-2 dB for ILDs. This is comparable to the range of JNDs found in adults. In contrast, on the lateralization task, children perform significantly worse than adults. Although children tend to use the same range of ITD and ILD values to indicate perceived stimulus location, their responses have greater variability across trials, suggesting either task difficulty or spatially ill-defined perception of sound images.

Conclusions

The novel finding in this study is that NH children showed binaural discrimination JNDs comparable to adults, suggesting that binaural sensitivity is mature by 8 years of age, even with degraded stimuli. However, the ability to utilize binaural cues for identifying perceived intracranial locations is immature in NH children. Because lateralization is proving to be a more challenging task than discrimination, it may be a better task for assessing binaural maturity. This work offers an important benchmark for future studies on binaural sensitivity in children with bilateral CIs.

METHODS

- Subjects were tested on three different stimuli while listening through Etymotic ER-2 headphones.
- Prior to beginning the experiments, each subject was familiarized with the range of ITDs and ILDs. They were asked to point on their head where the sound was heard.

Stimuli	Description	Rationale
Spondees	Disyllabic words (hotdog, toothbrush...)	To compare free field data to headphone data
Transposed Tones	4 kHz carrier tone modulated at a rate of 125 Hz.	To investigate response to stimuli with only envelope ITDs and to compare with adult lateralization data
Gaussian Enveloped Tone (GET) Pulse Train	4 kHz center frequency, 100 pps	To investigate lateralization using a CI simulation in NH children.

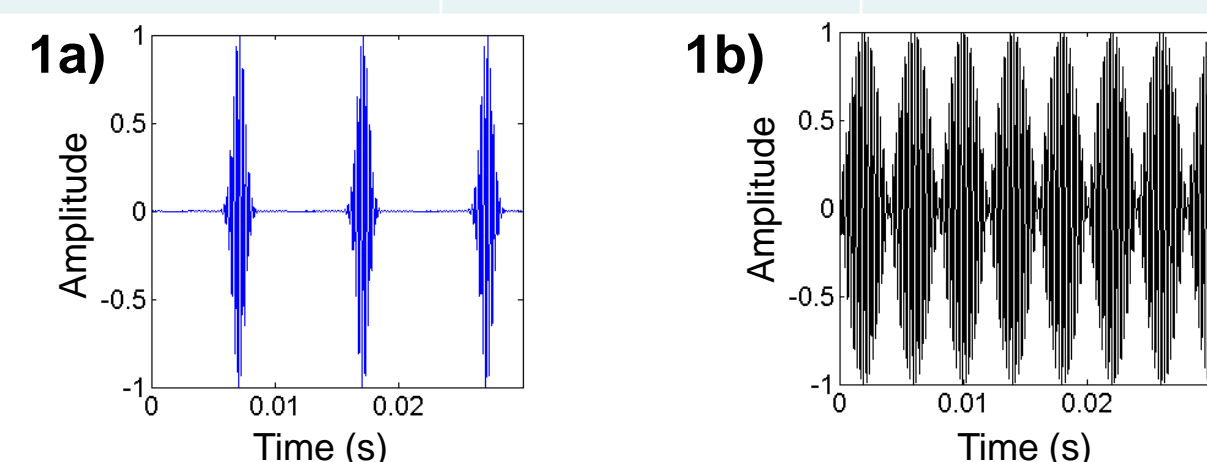
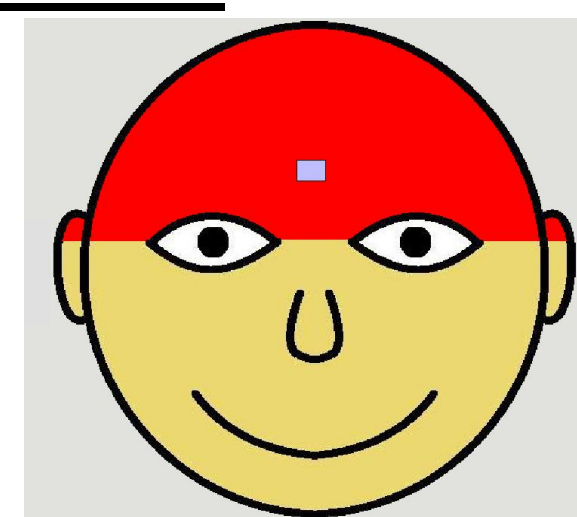


Figure 1: Gaussian (a) and Transposed (b) waveforms

Experiment 1: Lateralization

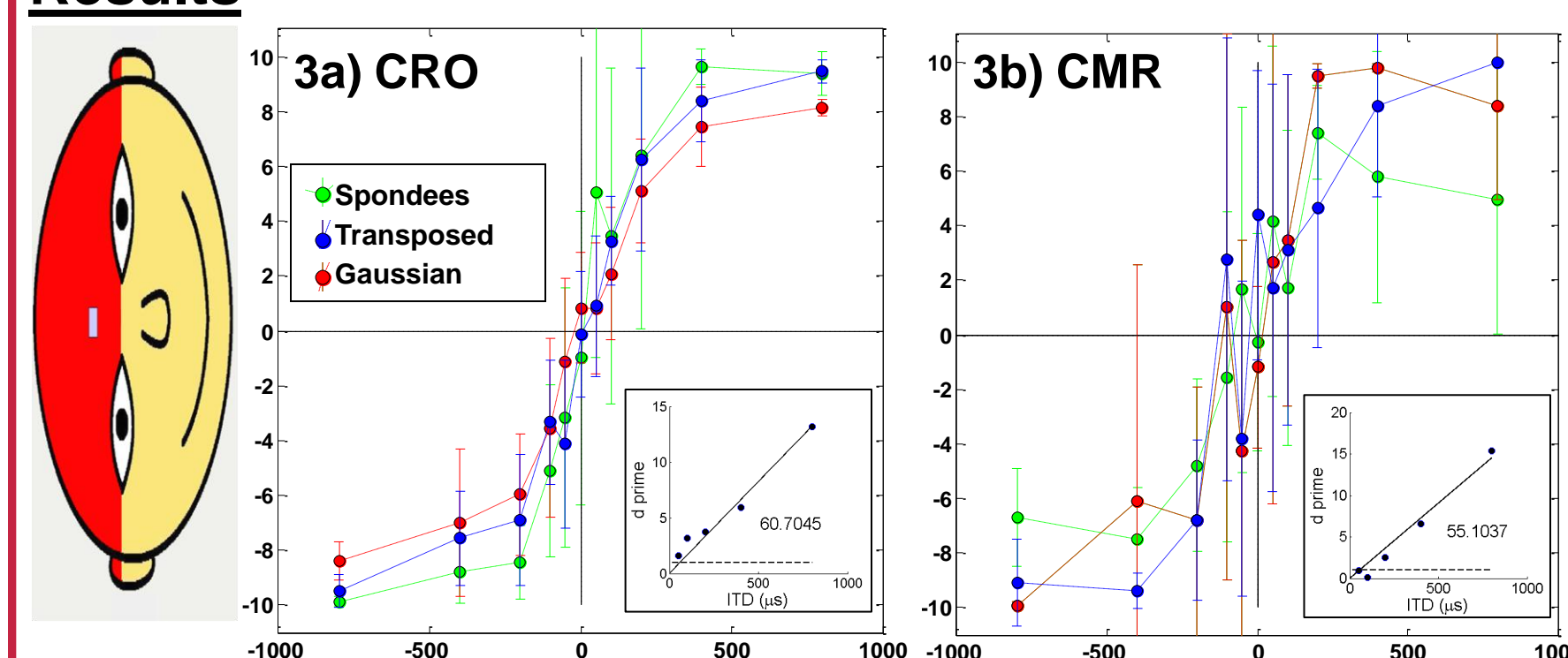
Methods



- Subjects were given ten repetitions of the following conditions for all three stimuli.
 - ITD Conditions
 - 0, ± 50 100, 200, 400, 800 µs
 - ILD Conditions
 - 0, ± 1.5, 3, 6, 9, 15 dB

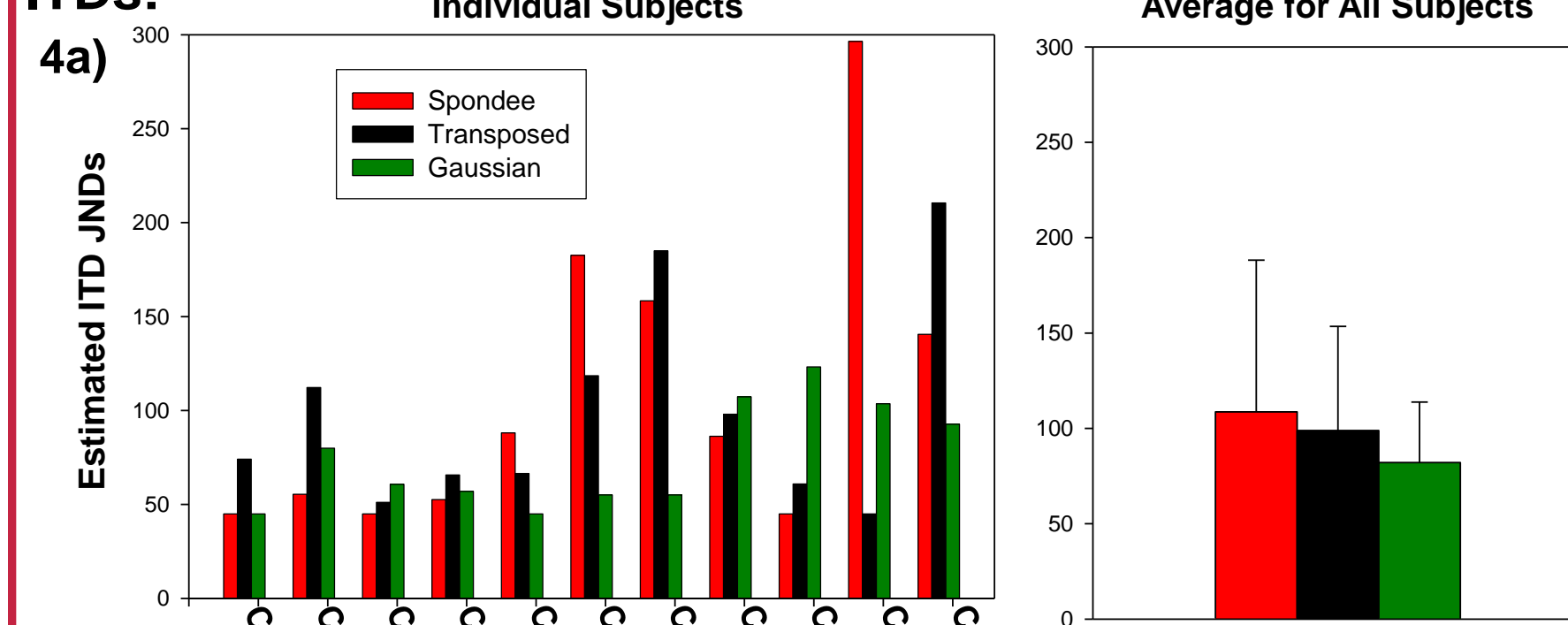
Figure 2: Graphical user interface used to capture the perceived lateral position of the stimuli in the lateralization experiment.

Results



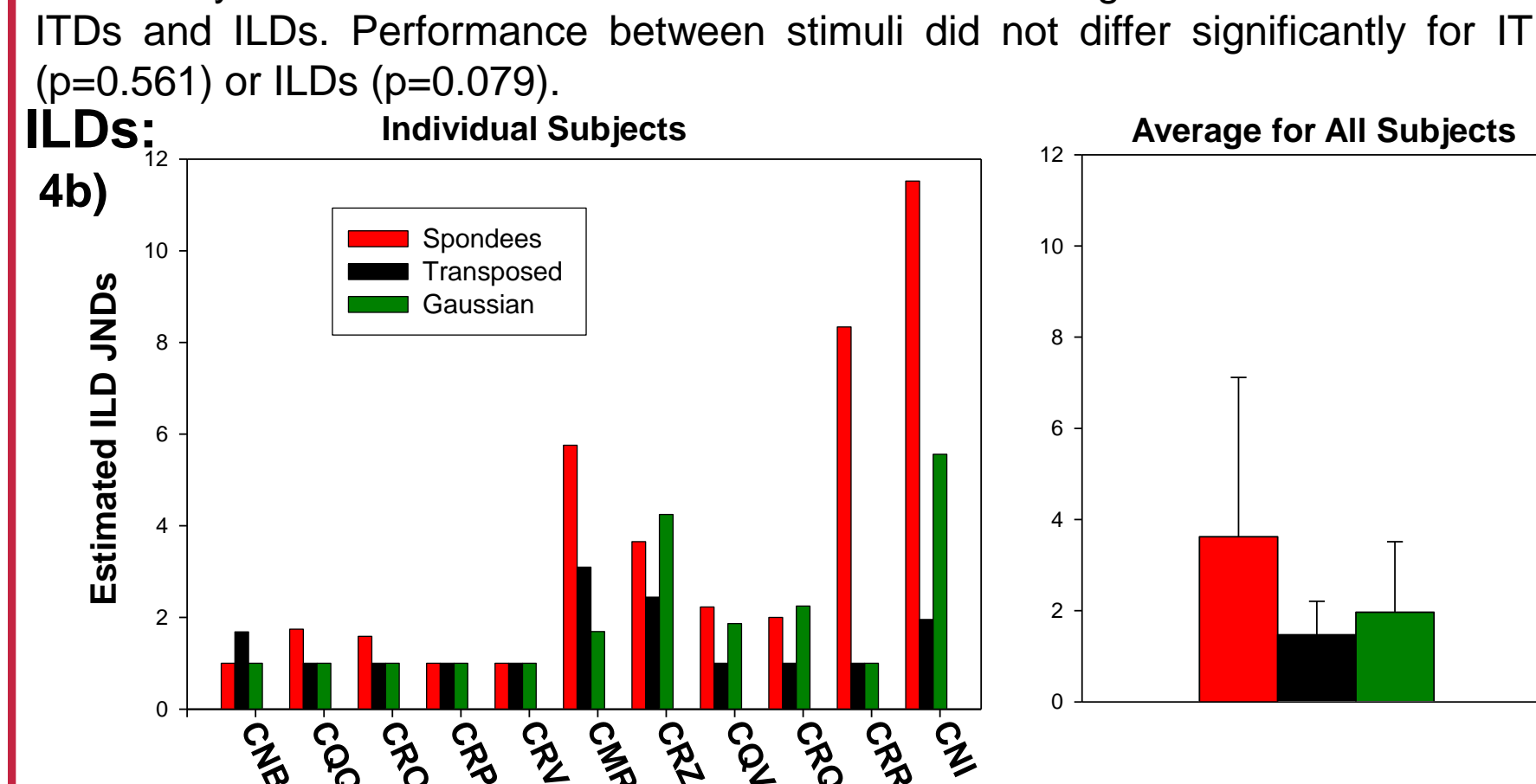
Figures 3a&b: Examples of raw data for ITD lateralization from two subjects. The 3 stimuli are shown. High variability was observed, both between and within subjects.

ITDs:



- The variability between children, for both ITDs and ILDs, suggests that while binaural sensitivity in some children is fairly mature, it is still developing in other children.
- A one-way ANOVA was used to test for differences among the three stimuli for both ITDs and ILDs. Performance between stimuli did not differ significantly for ITDs ($p=0.561$) or ILDs ($p=0.079$).

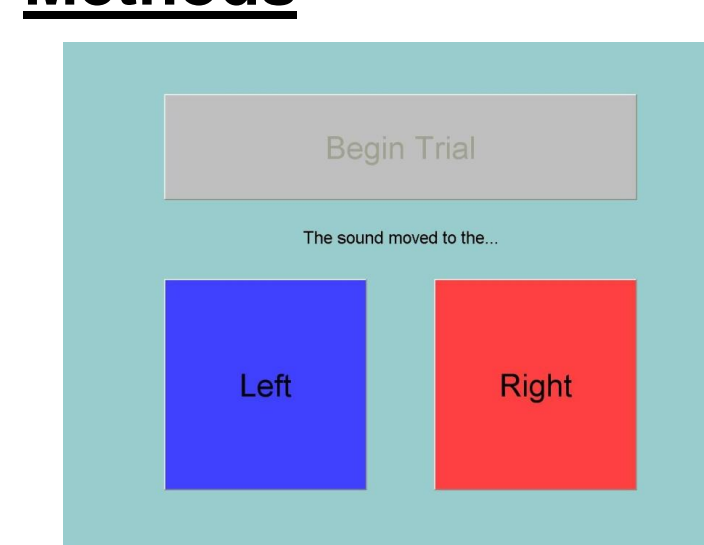
ILDs:



Figures 4a&b: Estimated JND values for individual subjects and group trends for ITDs and ILDs, respectively. JNDs were estimated using a d' analysis (see inset in Figure 3).

Experiment 2: Discrimination

Methods



- An adaptive two down, one up track was used, where the last of 6 reversals were averaged to determine the subjects JND for ITDs and ILDs.
- Transposed and Gaussian stimuli were used. Subjects responded by indicating whether the sound moved to the right or the left.

Figure 5: Graphical user interface used for discrimination experiment.

Results

ITDs:

- A paired t-test found no significant differences between Gaussian and Transposed ITD JNDs ($p > 0.05$).

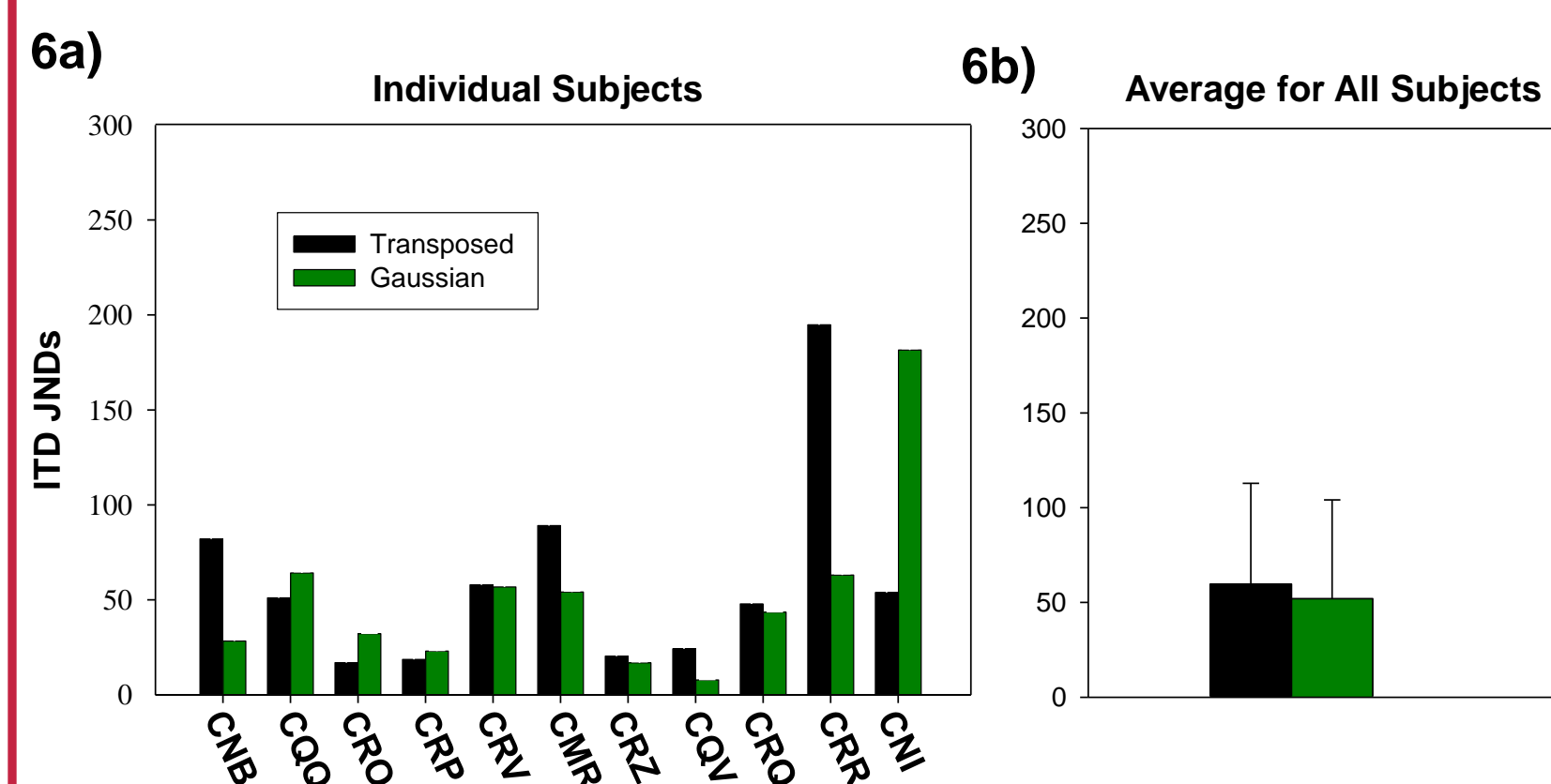


Figure 6a: ITD JNDs for the Transposed and Gaussian stimuli by subject. Figure 6b: Average ITD JND across all subjects.

ILDs:

- An interaction was found between binaural cue and stimulus type. A paired t-test showed ILD JNDs were significantly higher for Gaussian stimuli than Transposed stimuli ($p < 0.05$), indicated with an asterisk (*).

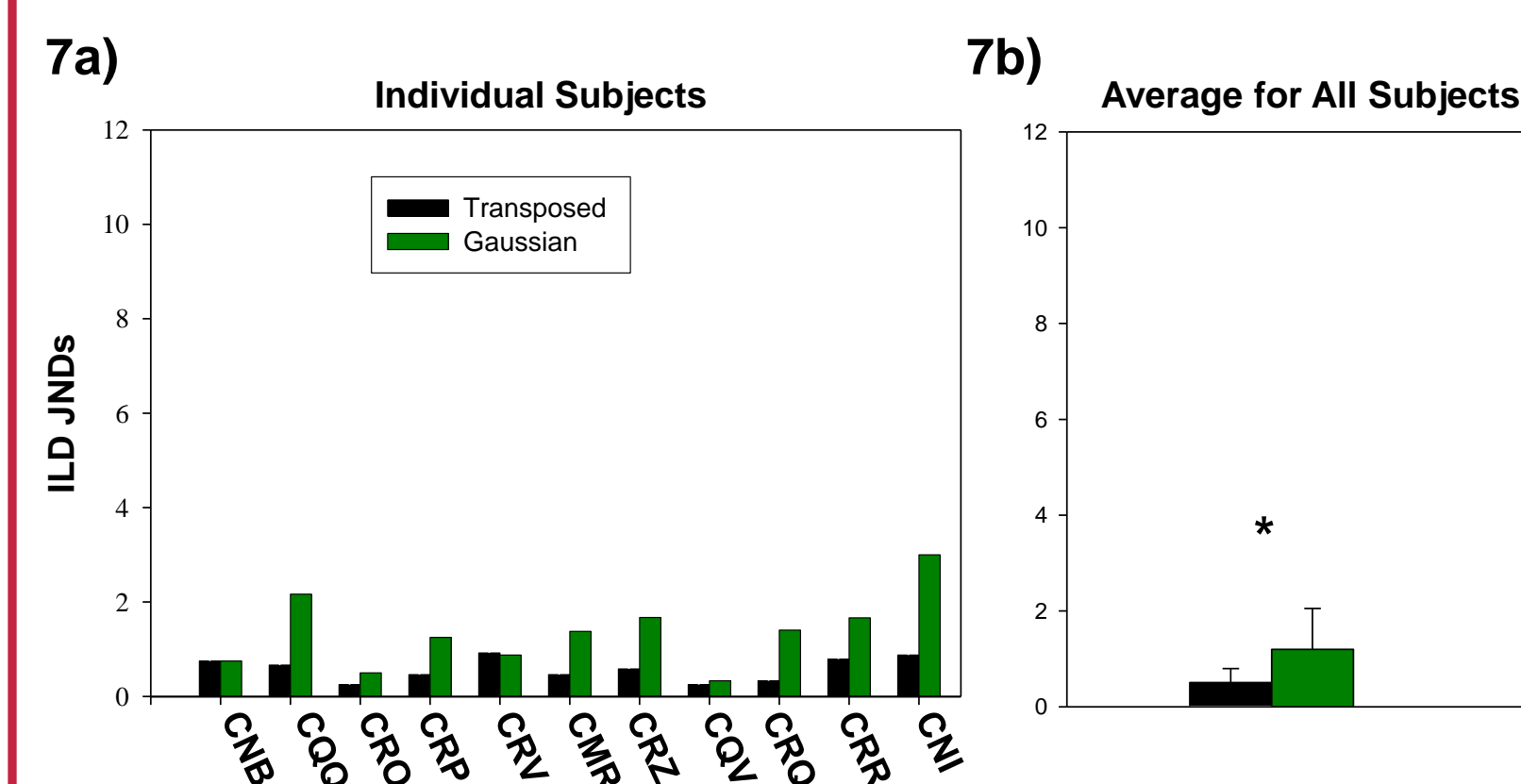
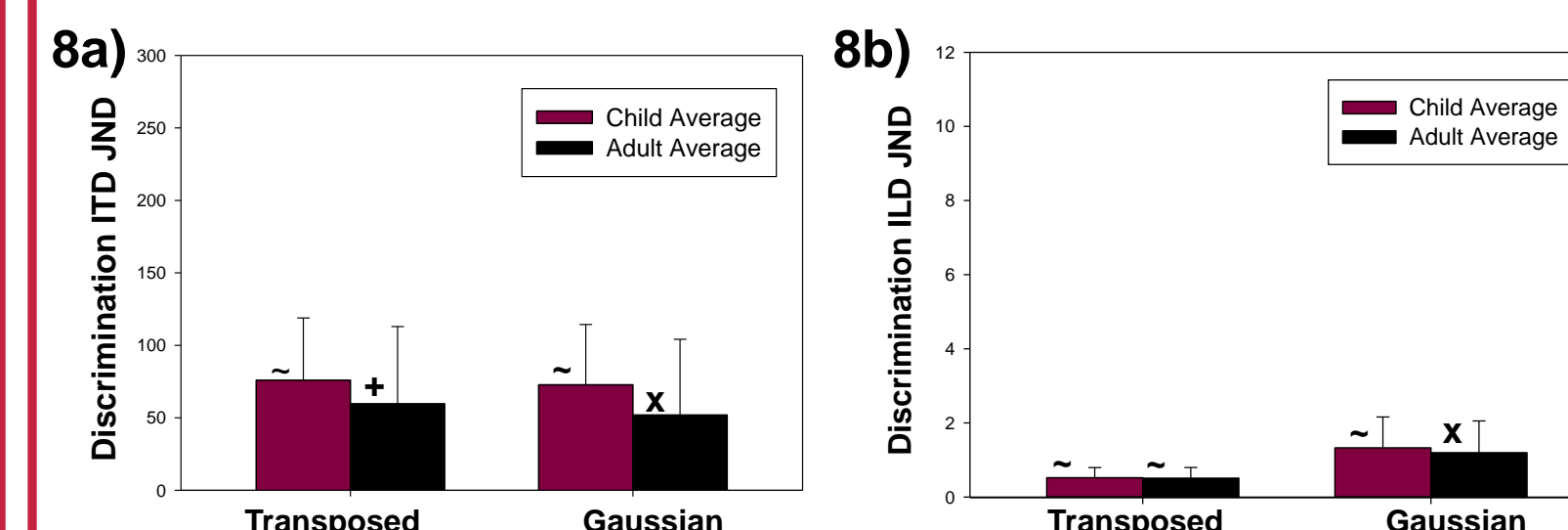


Figure 7a: ILD JNDs for the Transposed and Gaussian stimuli by subject. Figure 7b: Average ILD JND across all subjects.

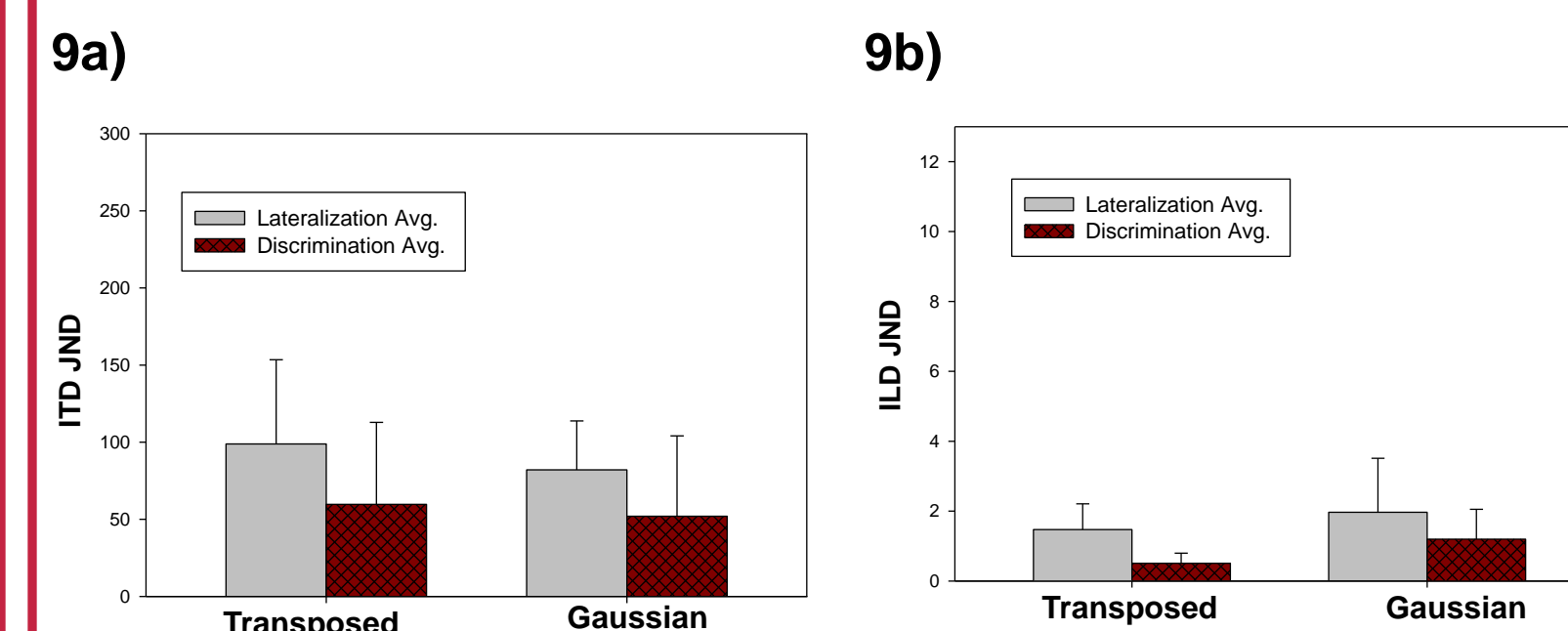
Comparison across age and condition

- On tasks of discrimination, a t-test found no significant differences ($p > 0.05$) between adults and children for either condition or stimuli. This suggests adult-like performance on tasks of discrimination.



Figures 8a&b: Average discrimination ITD and ILD JNDs for Transposed and Gaussian stimuli for children and adults. ~: Data taken from current study x: Data taken from Kan et al., 2011 +: Data taken from Bernstein & Trahiotis, 2002.

- A paired t-test found no significant differences on tasks of lateralization compared to tasks of discrimination ($p > 0.05$).



Figures 9a&b: Average ITD and ILD JNDs for Transposed and Gaussian stimuli comparing lateralization to discrimination.

CONCLUSIONS

- NH children are able to utilize the same range of ITDs and ILDs as adults on tasks of lateralization regardless of stimulus type.
- Binaural sensitivity at a young age is task dependent. Lateralization tasks had similar results to tasks of discrimination, but showed more variability than the discrimination tasks.
- On discrimination tasks, children showed sensitivity to ITDs and ILDs comparable to adults, even with degraded stimuli.
- Studies of children with BICIs could reveal factors other than binaural maturation, such as neural degradation. This work offers an important benchmark for future studies on children with BICIs.

REFERENCES

- Bernstein, L.R., & Trahiotis, C. (2002). Enhancing sensitivity to interaural delays at high frequencies by using "transposed stimuli". *J Acoust Soc Am*, 112, 1026-1036.
- Kan, A., Stoelb, C., Goupell, M.J., Litovsky, R.Y. "Effect of Mismatched Place-of-Stimulation on Binaural Sensitivity in Bilateral Cochlear-Implant Users", Presented at the Conference on Implantable Auditory Prostheses, CIAP2011, Pacific Grove, CA., July 2011

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