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Assessing Sound Source Localization in Listeners with Bilateral Cochlear Implants

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Introduction

- Listeners with **bilateral cochlear implants (BICIs)** exhibit *different* sound source localization than those with normal hearing (NH; Fig. 1).
  - Methods of analysis developed for NH may not be optimal for BICI
  - Implications for everyday listening (e.g., poorer localization at far angles, bias toward one side, greater variability in perceived location)

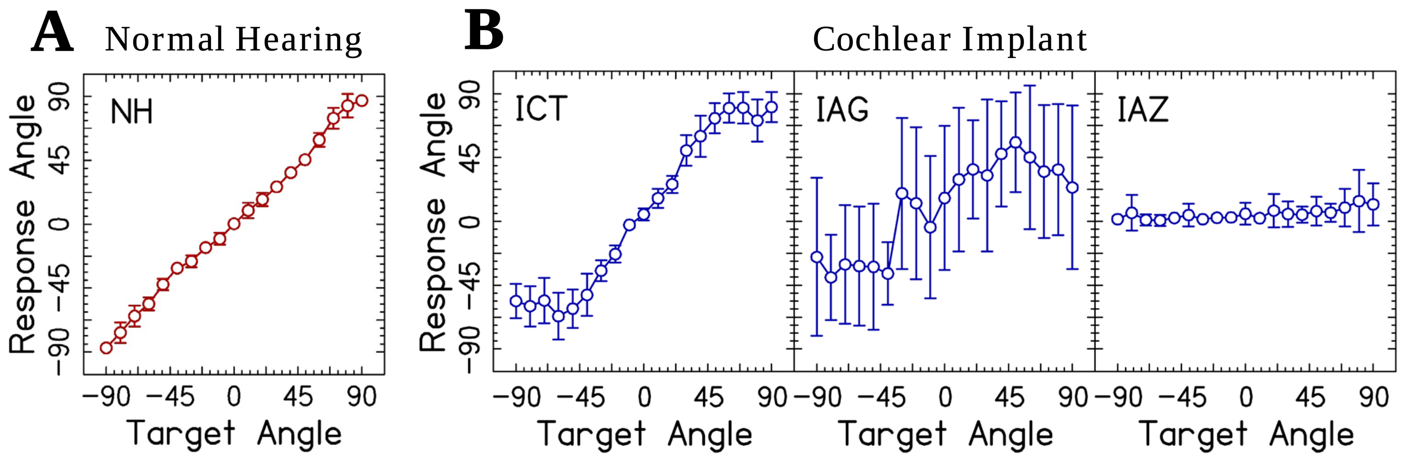


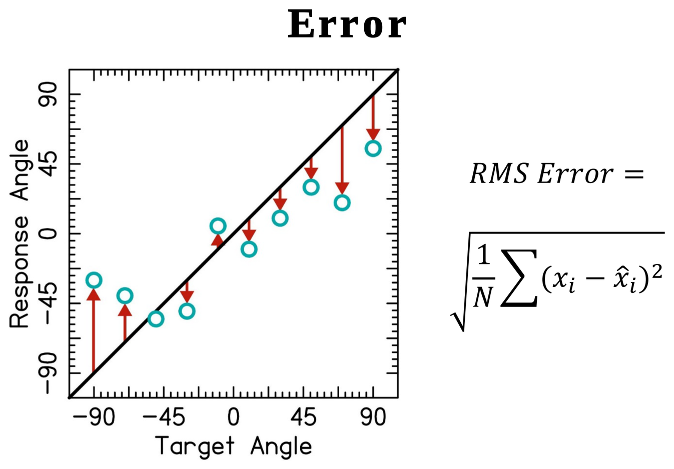
Fig. 1: Example data from individual listeners with NH (A) or BICIs (B). The x-axis indicates the location where the sound was presented. The y-axis indicates the perceived location from the subject. Error bars represent ± 1 standard deviation

- Characterizing changes with localization that depend upon **patient-dependent factors** could improve our ability to counsel patients.
  - Age at onset of deafness [1-2]
  - Delay in implantation between ears [3-4]

Goal: Compare four statistical approaches for characterizing localization performance to determine how localization ***patterns*** might be explained by patient-dependent factors.

Statistical Approaches

1. Root-Mean-Square (RMS) Error

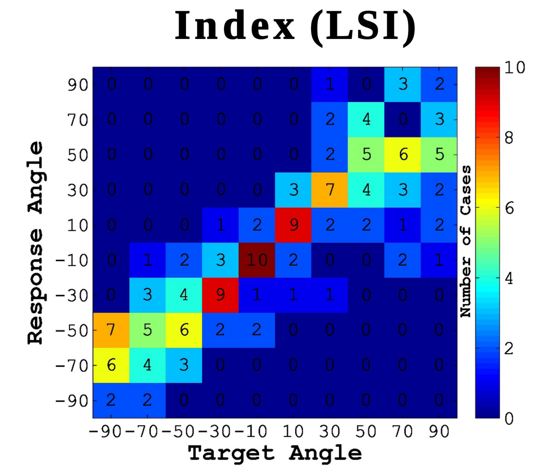


$$RMS\ Error = \sqrt{\frac{1}{N}\sum(x_i - \hat{x}_i)^2}$$

RMS error is the average error by angle. Here x_i and $\hat{x}_i$ are the target and response angles, and N is the number of data points.

- Standard for NH [5] and commonly reported in BICI literature

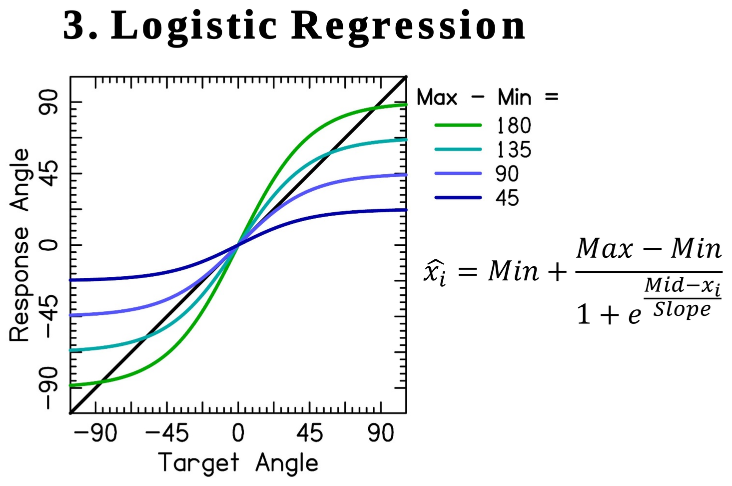
2. Localization Sensitivity Index (LSI)



LSI is the average of the d' for responses between all pairs of target angles.

- Proposed solution for BICIs [6]

3. Logistic Regression

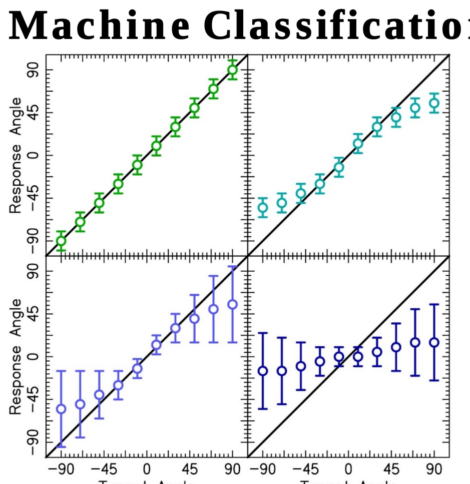


$$\hat{x}_i = Min + \frac{Max - Min}{1 + e^{\frac{Mid - x_i}{Slope}}}$$

Each curve shows changes in the parameters of the four-parameter logistic equation on the right. x_i and $\hat{x}_i$ are defined in RMS caption.

- Model to describe localization function shape [7]

4. Machine Classification



Panels show different categories of response based on mean or variance at each target angle.

- Sort into previously described categories [6]

Significance: Each statistical approach indexes different aspects of performance (i.e., accuracy, confusions, and shape of function).

Dataset & Methods

- Participants: 48 patients with BICIs
- Task: Perceived location was indicated on a touch-screen
  - Presented in free-field
  - 19 speakers from ± 90 degrees in 10 degree steps
  - 15 repetitions per speaker
- Stimuli: Trains of 4 pink noise bursts
  - 170 ms each, with 50 ms inter-stimulus interval
  - 50 dB SPL(A) ± 4 dB level rove and ± 10 dB spectrum rove

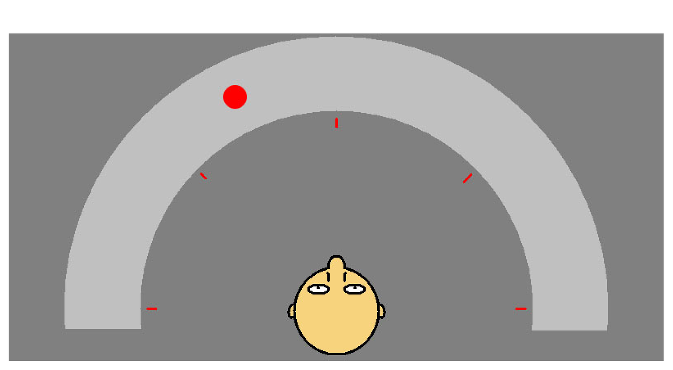


Fig. 2: Illustration of experimental interface. Listeners responded with perceived location on the semicircular arc.

Dataset Visualization

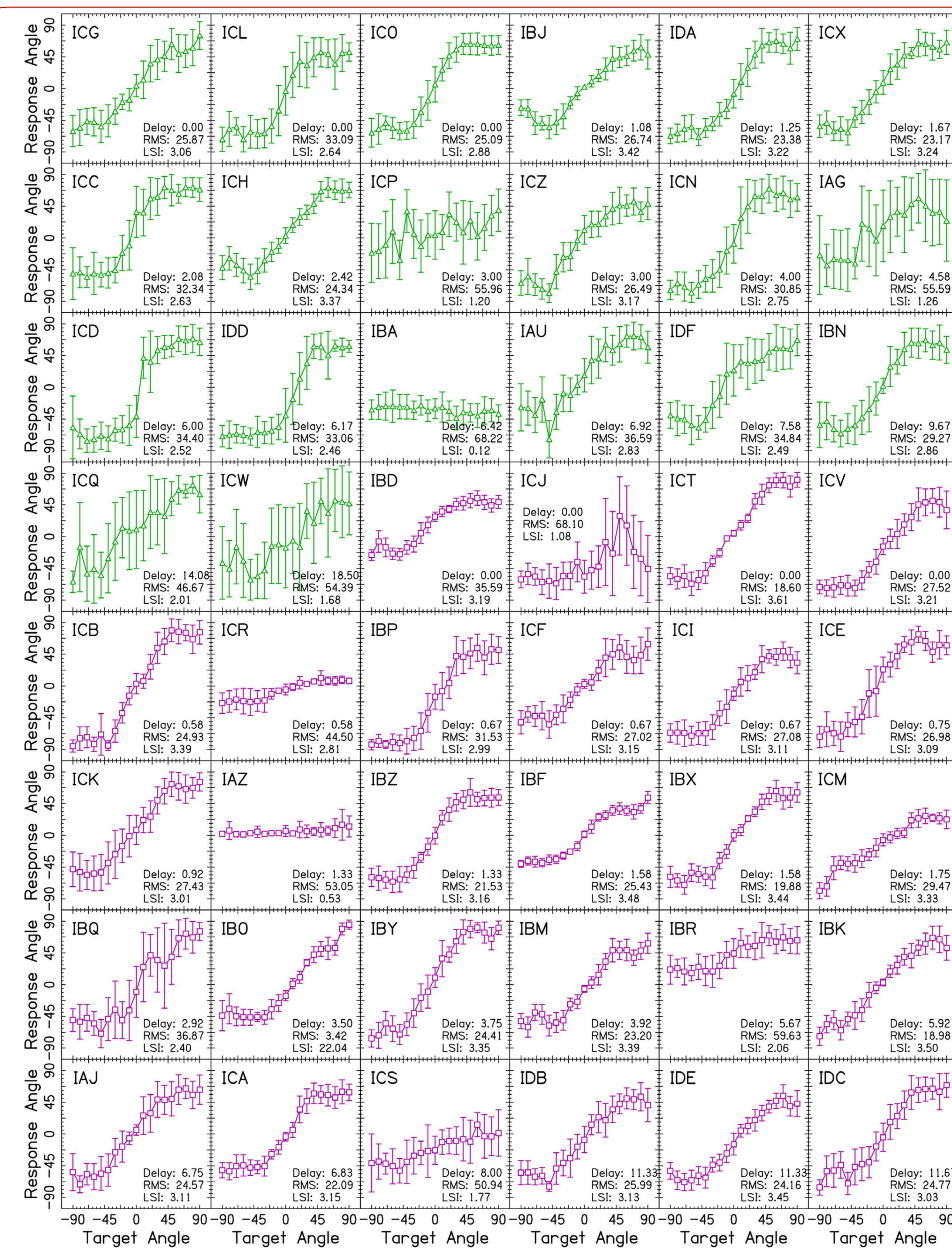


Fig. 3: Localization performance for individual patients with BICIs plotted as in Fig. 1. Each panel corresponds to a different individual whose subject code is given in the top-left. Delay in implantation between the ears in years, average RMS error, and LSI are given in the bottom-right corner.

- Variability across subjects, with some consistent trends (Fig. 3):
  - Greater variability and errors at lateral target angles
  - Tendency for some subjects to respond in the center for all targets
  - Larger standard deviations compared to NH (c.f., Fig. 1A)

Results: Errors and Confusions

1. RMS Error

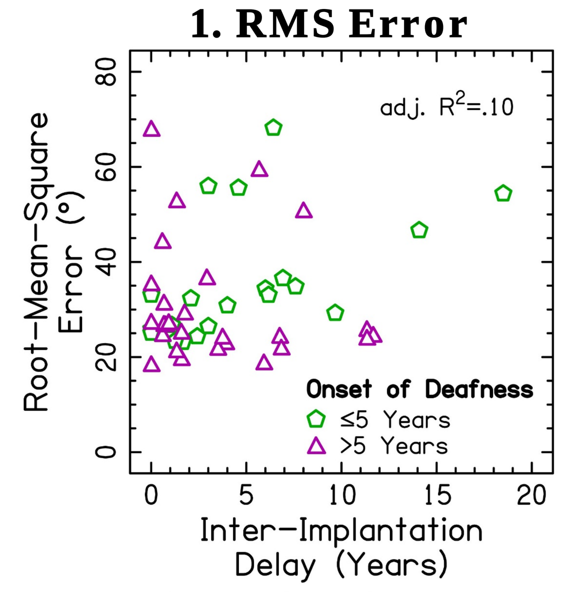


Fig. 4: Relation between RMS error and patient-dependent factors.

2. LSI

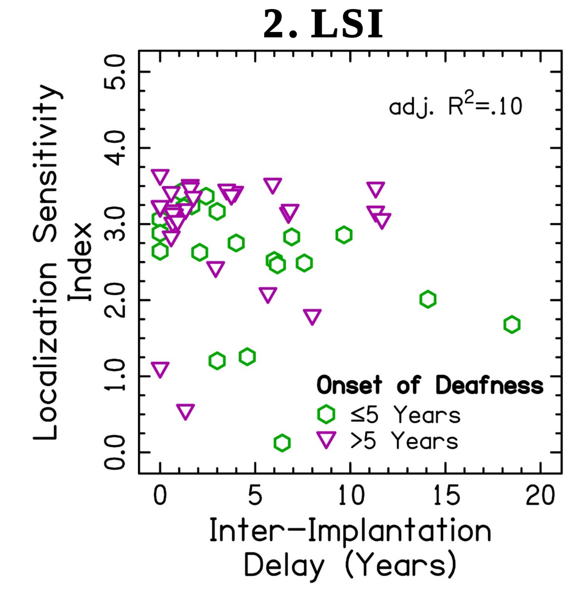


Fig. 5: Relation between LSI and patient-dependent factors.

- Results with overall RMS error (Fig. 4) or LSI (Fig. 5) show no relationship with patient-dependent factors
- High correlation between average RMS and LSI ($R^2 = .88$)
- Previous report shows relationship with RMS across central target angles [7]
  - Lack of effect due to failure to account for changes with target angle?

Alternative to correlation analysis: multi-level, quadratic regression

- Included target angle and squared target angle in regression to predict log(RMS error)
  - Squared term accounts for errors at lateral target angles
- Revealed significant effect of inter-implantation delay and interaction with age of onset of deafness (Table 1)

Effect	Estimate	t	p
Intercept	3.05400	51.01	**<.0001**
Inter-Implantation Delay	0.04913	5.67	**<.0001**
Age of Onset	-0.13010	-1.72	>.05
Target Angle	0.00189	1.03	>.05
Target Angle Squared	0.0005	3.55	**<.001**
Inter-Implantation Delay x Age of Onset	-0.04941	-3.87	**<.001**

Table 1: Regression results. The log(RMS error) for each target angle was included as dependent variable and 858 degrees of freedom. Transformation of dependent variable prevented violation of normality assumption.

Results: Shape of Localization Function

3. Logistic Regression

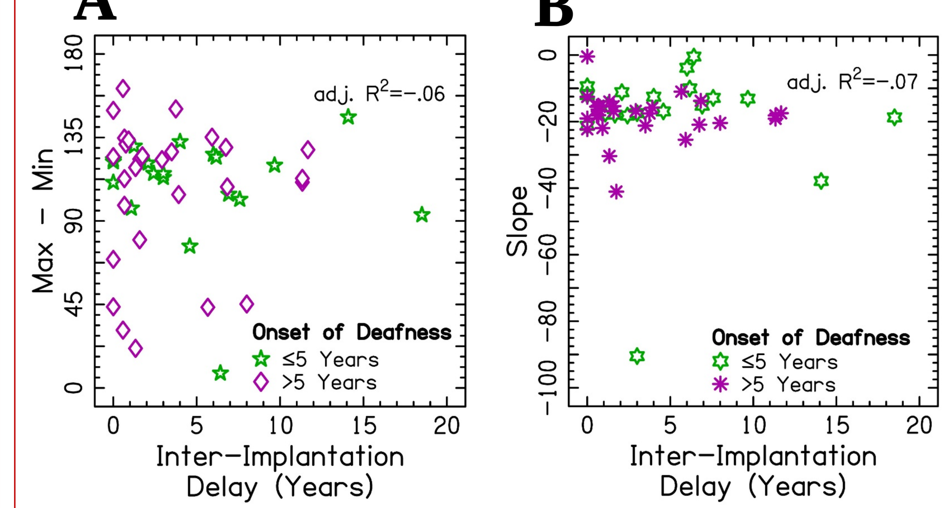


Fig. 6: Parameter estimates from logistic fits for Max - Min (A) response angle and Slope (B).

- Considerable variability in logistic parameters
  - Logistic fit may be useful for distinguishing localization performance
- No relationship between logistic parameters and patient-dependent factors

4. Machine Classification

- Raw data from each subject compared against the 20 categories of response (50 repetitions; Fig. 7) using machine classification
  - Categories based on changes with development noted in, but did not correspond with LSI [6]
- Unsupervised machine learning algorithm (partitioning around medioids) used to assign one subject to one of the twenty categories
- Process repeated 50 times, and the mode was taken for each subject

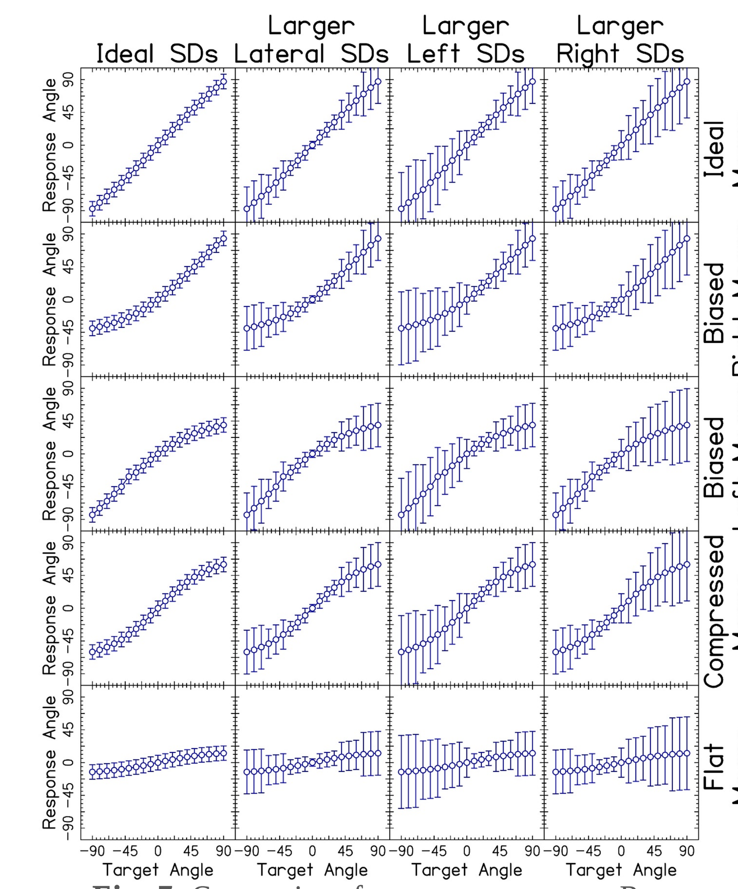


Fig. 7: Categories of response patterns. Rows correspond to distribution of means. Columns correspond to distribution of standard deviations.

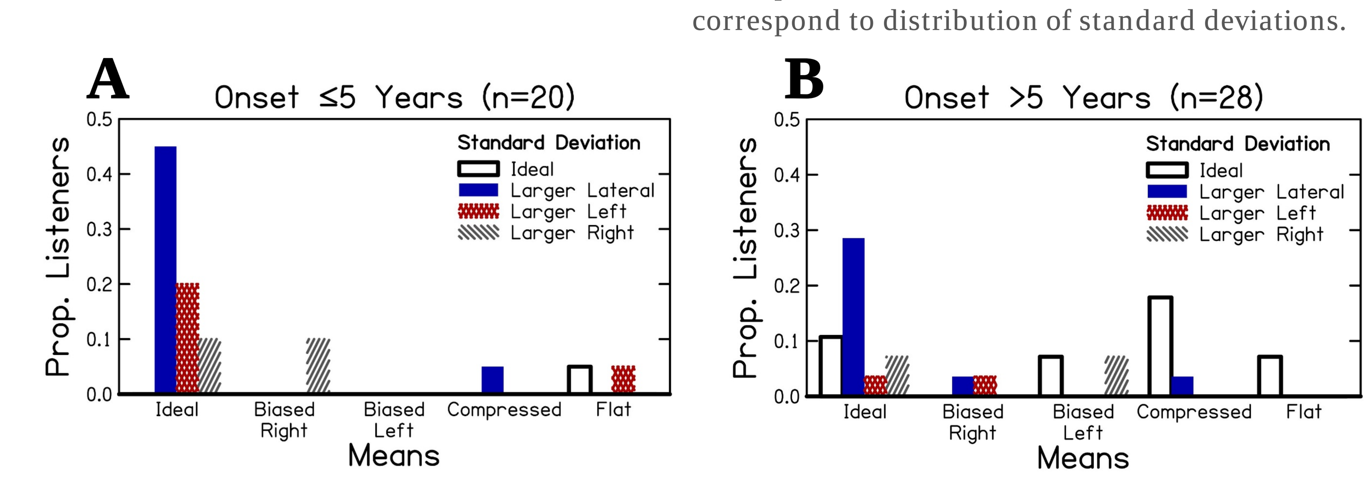


Fig. 8: Histogram of group assignments for earlier (A) and later (B) deafened patients. Based on categories in Fig. 7.

- Most patients did not exhibit ideal localization performance (Fig. 8)
- Patients that acquired deafness ≤5 years had accurate means but were more variable at lateral target angles
- Patients that acquired deafness >5 years had heterogeneous localization outcomes
  - More individuals with smaller variability (i.e., ideal standard deviations)

Summary

- Prior approaches have been unable to illuminate characteristic differences in localization patterns associated with patient-dependent factors with BICIs.

1. **Root-mean-square error** showed poorer performance when patients had a longer delay in implantation between each ear, which was compounded when patients acquired deafness ≤5 years (Table 1).
2. **Localization sensitivity index** was highly correlated with RMS error.
3. **Logistic regression** showed shape of localization varies across patients, but may not be related to the patient-specific factors investigated in this study (Fig. 6).
4. **Novel approach: Machine classification** showed high variability in localization responses at lateral locations for patients that acquired deafness ≤5 years, and heterogeneous outcomes for patients that acquired deafness >5 years (Fig. 8).
   - Localization patterns influenced by patient-dependent factors

- Patient care might be optimized by considering these characteristic differences in localization performance.
  - Each approach has different strengths that should be considered depending upon the research question.

References

1. Litovsky, R. Y., Jones, G. L., & Agrawal, S. (2010). *J Acoust Soc Am*, *127(1)*, 400-414.
2. Laback, B., Egger, K., & Majdak, P. (2015). *Hear Res*, *322*, 138-150.
3. Reeder, R. M., Firszt, J. B., Holden, L. K., & Strube, M. J. (2014). *J Speech Lang Hear Res*, *57(3)*, 1108-1126.
4. Nopp, P. Schleich, P., & D'Haese, P. (2004). *Ear Hear.*, *25*, 205-214.
5. Yost, W. A., Loiselle, L., Dorman, M., & Burns, J. (2012). *J Acoust Soc Am*, *133(5)*, 2876-2882.
6. Zheng, Y., Godar, S. P., & Litovsky, R. Y. (2015). *PloS One*, *10(8)*, e0135790.
7. Jones, H., Kan, A., & Litovsky, R. Y. (2014). *Trend Hear*, *18*, doi:10.1177/2331216514554574.

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