Investigating how factors such as patients' hearing history and pitch matching between the ears may affect binaural sensitivity in bilateral cochlear implant listeners

Tanvi Thakkar[1], Alan Kan[1], Matthew Winn[1], Matthew J. Goupell[2], and Ruth Y. Litovsky[1]
[1]University of Wisconsin-Madison, Madison, WI [2]University of Maryland, College Park, MD, USA
e-mail: tthakkar@wisc.edu

2015 Conference on Implantable Auditory Prostheses Lake Tahoe, CA
PS #R34

WAISMAN CENTER
Binaural Hearing and Speech Laboratory

INTRODUCTION

- Individuals with bilateral cochlear implants (BiCIs) show large variability in their sensitivities to interaural timing differences (ITDs) [1,2]. This variability may arise from a number of different factors, which include:
  1. Patients' history: years of bilateral hearing impairment, experience with BiCIs etc.
  2. Surgical factors: different insertion depths between the ears.
  3. Hardware factors: Lack of synchronization between processors
- ITD sensitivity can be influenced by place of stimulation: the same numbered electrodes between the ears can stimulate different places along the cochlea[3] (Fig. 1).

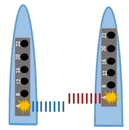


Figure 1: Electrodes of the same number between the ears could be perceived as different pitches because of different insertion depths.

- Pitch-matching tasks are often used to choose pairs of electrodes that approximately stimulate the same places along the cochlea in each ear when measuring ITD sensitivity[4].
- However, there can be high inter-subject variability in pitch-matching outcomes, which can affect which pairs of electrodes are chosen. Hence, a poorly chosen pair could lead to poor ITD sensitivity.

The aim of this study was to investigate if variability in ITD sensitivity found in BiCI users is related to (a) patients' hearing histories, and (b) ability to pitch match between the two ears.

METHODS

- **Listeners:** 36 BiCI listeners with Cochlear devices.
- **Stimuli:** 300 ms constant amplitude pulse trains presented at 100 pps.
  - Delivered to the listeners using synchronized L34 processors.
  - Biphasic pulses with a 25-µs phase duration with monopolar stimulation.
- **Experiment(s):**
- **Pitch magnitude estimation (PME):**
  - Pitch ratings from 0(low)-100(high) with randomized stimulation on each electrode in either ear at 10 reps per ear (Fig 2a).
- **Direct pitch comparison (DPC):**
  - Three cochlear locations (Apex, Middle and Base) were selected in the left ear while the right ear was mismatched by 0 ± 2, and ± 4 electrodes for comparison.
  - Pitch-matching options are shown in Fig 2b.
- **ITD Discrimination:**
  - 2-interval 2-alternative forced-choice task.
  - Listeners reported whether they heard the sound move to the left or right.
  - ITDs = ±100, ±200, ±400, ±800 µs
  - A psychometric function was fit to the percent correct data to obtain a just-noticeable difference (JND) threshold at 71% using a bootstrap procedure[5].

a)

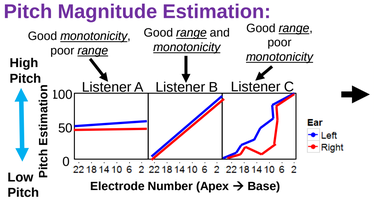
b)

Figure 2: (a) PME task screen (b) DPC task screen.

QUANTIFYING RESPONSES TO PITCH TASKS

Example responses in pitch tasks:

Pitch Magnitude Estimation:



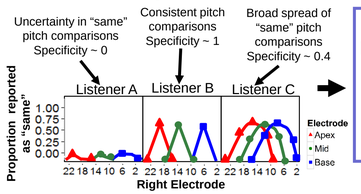
PME Slope = slopes of pitch magnitude estimation for each ear

PME Slope represents the range of pitch in each ear that listeners perceive from basal-most to apical-most electrodes.

Represented by…

Reflects…

Direct Pitch Comparisons:



Specificity of "same" pitch responses = mean difference in proportion of "same" responses between the *chosen* electrode pair and adjacent pairs.

Specificity represents the *consistency* of responses for the *chosen* electrode pairs to be perceived as the same pitch.

RESULTS

ITD Thresholds for all BiCI listeners

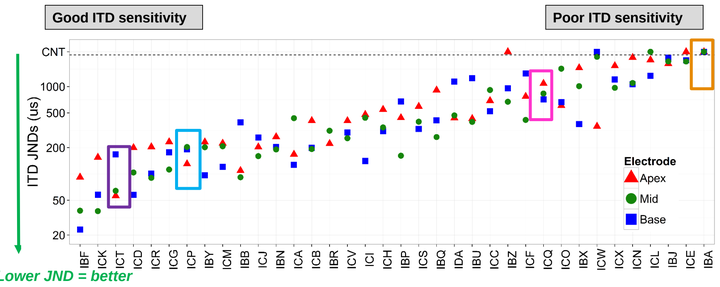


Figure 3: ITD JNDs plotted for each listener ordered from lowest thresholds to highest. Different symbols represent different cochlear locations. Thresholds not determined are labeled as "could not test" (CNT).

Incongruence in ITD thresholds and pitch measures: Different listeners demonstrated different combinations of ITD sensitivities, PME slopes, and specificity (highlighted by four listeners of different-colored boxes)

BiCI Listeners:

ID	Age	Age of Onset HL	Yrs with BiCI	Etiology	ID	Age	Age of Onset HL	Yrs with BiCI	Etiology
IBF	59	38	3	Hereditary	IBP	61	54	7	Meningitis
ICK	69	30	1	Noise	ICS	85	68	3	Unknown
ICT	20	18	2	Trauma	IBQ	80	44	6	Meniers
ICD	54	3	4	Unknown	IDA	46	5	1	Nerve damage
ICR	59	27	2	Radiation	IBU	56	20	4	Progressive
ICG	50	2	9	Progressive	ICC	66	2	4	Congenital
ICP	50	3	1	Nerve Damage	IBZ	44	30	4	Unknown
IBY	48	41	0.66	Progressive	ICF	70	21	1	Otosclerosis
ICM	59	20	1	Progressive	ICQ	19	4	1	Meningitis
IBB	44	23	3	Progressive	ICO	32	4	1	Progressive
ICJ	63	13	3	Childhood illness	IBX	70	40	1	Ototoxicity
IBN	61	0	1	Unknown	ICW	21	0	1	Unknown
ICA	53	13	3	Progressive	ICX	74	0	2	Meniers
ICB	61	9	6	Progressive	ICN	40	4	2	Progressive
IBR	57	28	4	Ototoxicity	ICL	45	3	2	Measles
ICV	58	7	6.5	Sensorineural	IBJ	65	8	1	Unknown
ICI	54	31	3	Unknown	ICE	72	66	4	Unknown
ICH	32	2	5	Enlarged vestibular aqueducts	IBA	75	0	1	Progressive

Table 1: BiCI listeners and their demographics. Listeners ordered from best to worst ITD sensitivity.

Pitch Magnitude Estimation(s)

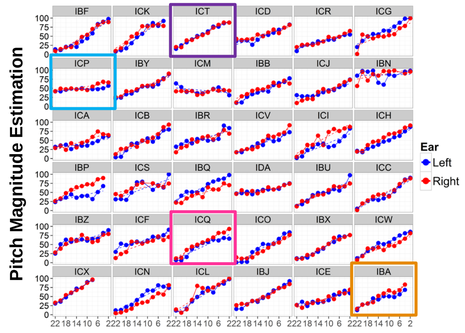


Figure 4: PME responses. Listeners ordered from best to worst ITD sensitivity.

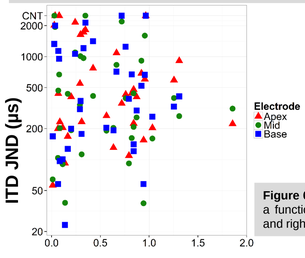


Figure 6: ITD JNDs plotted as a function of difference in left and right PME slopes.

Direct Pitch Comparison(s)

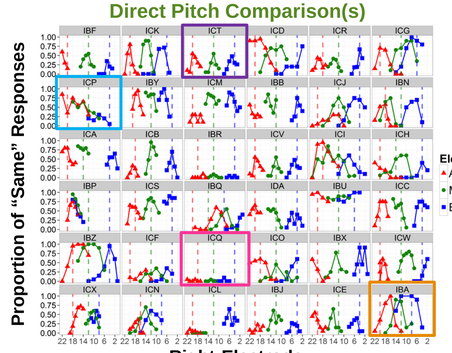


Figure 5: DPC measures. Listeners ordered from best to worst ITD sensitivity. Dashed line represents left electrode tested.

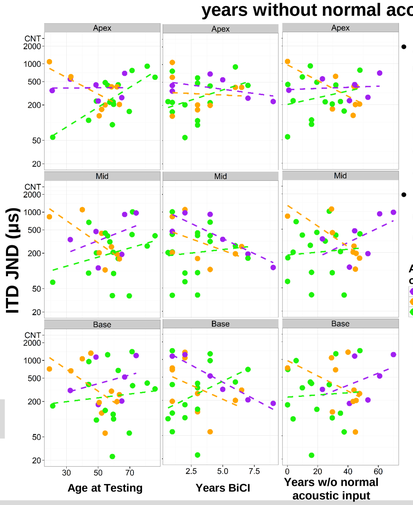
Figure 7: ITD JNDs plotted as a function of "specificity""

1) Does the ability to perform tasks such as pitch matching and pitch estimation alone predict ITD outcomes? No.

- Similarity of pitch perception between the ears (i.e. PME slope differences) or the "specificity" of pitch matching of the chosen pitch-matched pair were not directly related to ITD thresholds ($p > 0.05$ for all cochlear locations).
- No relationship was found between the PME slope differences and the "specificity" of pitch-matching ($p > 0.05$ for all cochlear locations).

2) Does hearing history account for ITD sensitivity instead?

ITD JNDs as a function of three predictors: age at testing, years with BiCI, and years without normal acoustic input



- **Age of Onset:** when listeners were grouped by early, childhood, and adult onset of deafness, ITD variability was not related to clinically-relevant predictors in Fig. 8 ($p > 0.05$); analyses was completed for listeners with JNDs < 1600 µs.
- Mean ITD JNDs were not significantly different ($p > 0.05$), based on age of onset (see Table 2.).

Age of Onset of deafness
- Early Onset (< 3 years)
- Childhood Onset (3-17 years)
- Adult Onset (>18 years)

	Early Onset		Childhood Onset		Adult Onset	
	Mean (µs)	Std. Dev.	Mean (µs)	Std. Dev.	Mean (µs)	Std. Dev.
Apex	607.4	519.0	400.8	320.4	437.1	417.6
Mid	498.8	363.7	738.4	791	299.7	259.6
Base	592.8	465.9	491.1	433.9	433	443.3

Table 2: Mean ITD JNDs for each group based on onset of deafness. Analyses for listeners with JNDs < 1600 µs.

Figure 8: ITD JNDs plotted for three predictors for listeners with JNDs < 1600 µs .

CONCLUSIONS

1. ITD thresholds do not appear to be related to listeners' perceptual mapping of pitch as stimulation is varied in the basal-to-apical dimension along the electrode array. Thus the impact of pitch matching on ITD sensitivity may be small.
2. Furthermore, ITD thresholds are not related to patients' hearing history.
3. The inability to account for the variation in ITD sensitivity might be due to a *greater plasticity* of pitch perception between the ears and the *lack of plasticity* in ITD sensitivity.

REFERENCES

1. van Hoesel RJ (2007). Sensitivity to binaural timing in bilateral cochlear implant users. Acoust Soc Am. Apr;121(4):2192-206.
2. Kan A., and Litovsky RY (2015). Binaural hearing with electrical stimulation. Hear Res. 2015 Apr;322:127-37.
3. Kan, A., Stoelb, C., Litovsky, R.Y., & Goupell, M.J. (2013). Effect of mismatched place-of-stimulation on binaural fusion and lateralization in bilateral cochlear-implant users. J. Acoust. Soc. Am. 134(4): 2923-2936.
4. Kan, A., Litovsky RY, Goupell MJ. (2015). Effects of interaural pitch matching and auditory image centering on binaural sensitivity in cochlear implant users. Ear Hear. 2015 May-Jun;36(3):e62-8.
5. Wichmann, F. A., and Hill, N. J. (2001). "The psychometric function: II Bootstrap-based confidence intervals and sampling," Percept. Psychophys., 63, 1314–1329.

ACKNOWLEDGEMENTS

We would like to thank all our participants and Cochlear Ltd for providing equipment and technical assistance.
This work is funded by NIH-NIDCD (R01 DC003083 to RYL), and NIH-NICHD (P30 HD03352 to Waisman Center).