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Investigating the effects of interaural place-of-stimulation mismatch and channel interaction in multi-electrode stimulation in bilateral cochlear implant users

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INTRODUCTION

- In bilateral cochlear implant (**BiCI**) users, interaural place-of-stimulation mismatch (**IPM**) can occur due to electrode array insertion depth differences in the two ears.
- Using single electrode stimulation, Kan *et al.* (2013) showed that with increasing IPM, a fused auditory image would be lateralized to one side despite zero interaural time and level difference (**ITD** and **ILD**, respectively). For some subjects, there was a breakdown of auditory image fusion with large IPM. When ITDs and ILDs were introduced, ITD lateralization was significantly degraded with 6 mm of IPM, but ILD lateralization remained relatively robust.
- In the case of multiple electrode stimulation, channel interactions can occur due to current spread along the basilar membrane.
- It is unknown how the combination of IPM and channel interactions will affect auditory image fusion and lateralization of ITDs and ILDs.
- We can hypothesize that with IPM, activating adjacent electrodes might aid in auditory image fusion because current spread will increase the amount of interaural overlap in the spatial excitation area. However, channel interactions may adversely affect the salience of binaural cues; thus, sound localization would benefit from activating electrodes that are farther apart.

METHODS

1. Bilateral CI Subjects

ID	Sex	Age	Years CI L	Years CI R	Implant Type L	Implant Type R	Etiology
IAJ	F	68	17	10	CI24M	CI24R(CS)	Unknown; progressive loss from birth
IBK	M	74	10	4	CI24R(CS)	CI24RE	Possibly hereditary and/ or noise induced
IBN	M	67	4	13	CI24RE	CI24R(CS)	Unknown; progressive loss from birth
ICA	F	54	4	11	CI24RE	CI24RE	Possibly fever; progressive since age 13
ICB	F	63	8	11	CI24RE	CI24RE	Possibly hereditary; progressive since age 9
ICG	F	51	10	10	CI24R(CS)	CI24R(CS)	Unknown; progressive loss from birth

2. Stimulus
- 300 ms, 100 Hz bi-phasic pulse train on two electrodes in each ear.
- Basal electrode in each ear was always stimulated first.
- Presented at perceived equal loudness, comfortable levels, using Nucleus Implant Communicator.

Fig 1. Electrode stimulation order

3. Conditions
- 2 electrode spacing conditions: small electrode spacing (2 electrodes) or large electrode spacing (6 electrodes).
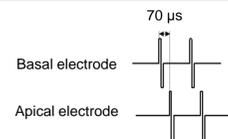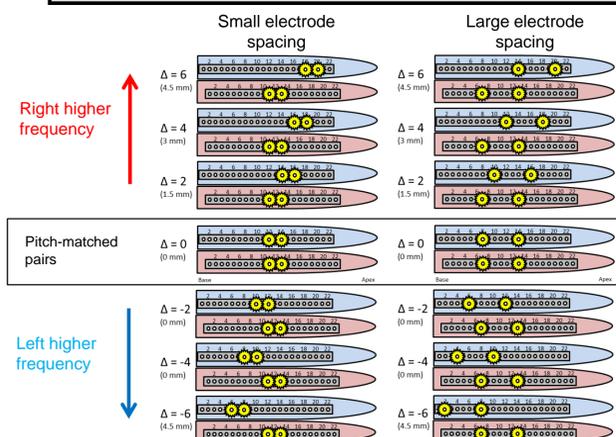- 7 mismatch conditions: Δ=0, ±2, ±4, ±6.

Fig 2. Interaural mismatch and electrode spacing conditions

FUSION

1. Methods
- Subjects responded with the number and perceived lateralization of sound sources heard.
- Stimulation presented on electrode pairs with ITD=ILD=0.
- 20 trials per IPM x 7 IPM x 2 interaction configurations (280 trials total), presented in random order.

2. Results
- Two out of six subjects (IAJ & IBK) perceived non-fused auditory images with positive IPM (Fig. 3). For these subjects, increasing IPM led to auditory images being perceived mostly on the left and right simultaneously (Fig. 4). All other subjects reported fused auditory images in all trials.
- With increasing IPM, fused auditory image were typically perceived on the side where stimulated electrodes were higher in frequency (Fig. 5).
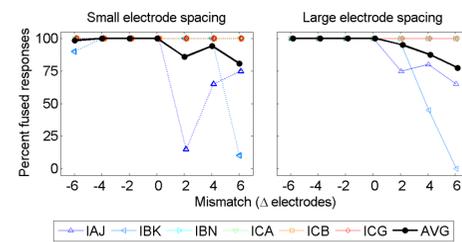
Fig 3. Percentage of fused auditory images

Fig 4. Perceived lateralization of unfused auditory images
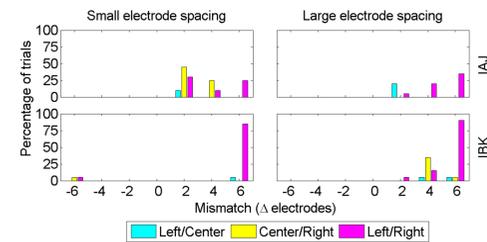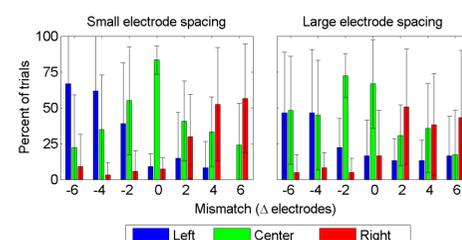
Fig 5. Perceived lateralization of fused auditory images

LATERALIZATION

1. Methods
- Subjects indicated number and perceived lateralization of sound sources on a picture of a head. When multiple sound sources were perceived, subjects ranked dominance of sound sources in their response.
- ITDs and ILDs were applied separately to stimuli:
  - Typical ITDs = 0, ±200, ±400, ±800 µs.
  - Typical ILDs = 0, ±2, ±5, ±10 Current units (CU).
- 10 trials per ITD/ILD x 7 IPM x 2 interaction condition, presented in a random order.

2. Results
- Most subjects perceived a single fused auditory image (Fig. 6).
- With no IPM, most subjects mapped the range of ITDs and ILDs to different lateral positions ranging from left to right in the head (Fig 7).
- With increasing IPM, subject's ability to perceive ITDs for auditory image lateralization was severely reduced but ILD lateralization appears unaffected by IPM (Fig 7 & 8).
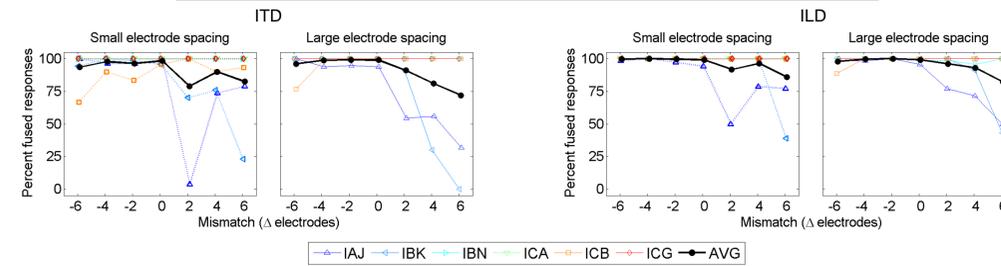
Fig 6. Percentage of fused auditory images

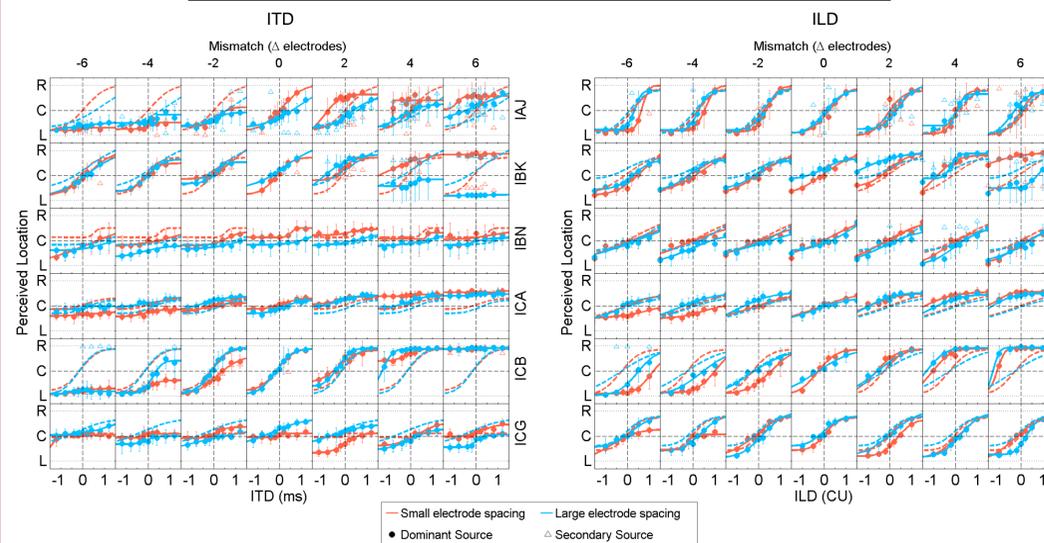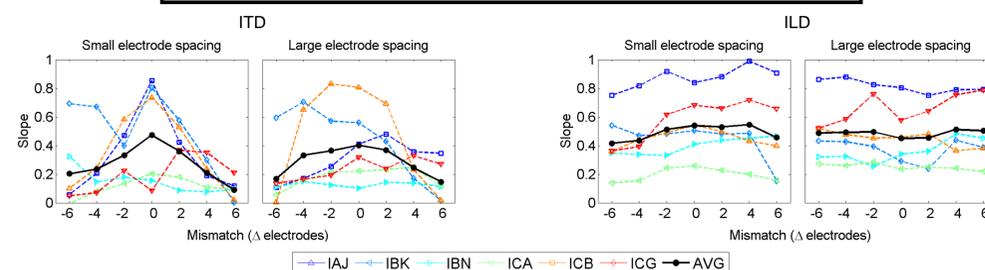**Fig 7.** Lateralization of auditory images with ITDs and ILDs

Fig 8. Slope of lateralization curves at ITD=0 µs and ILD=0 CU

EFFECT OF ELECTRODE SPACING

- Electrode spacing has little effect on auditory image fusion (Fig. 9) and the ability to use ITDs and ILDs for lateralization (Fig. 10).

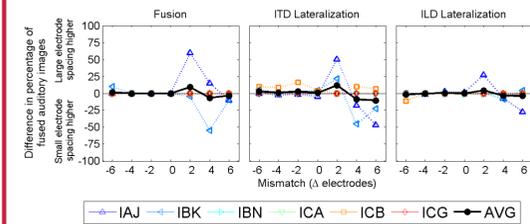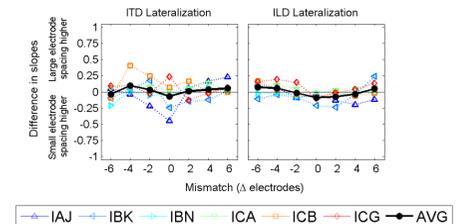**Fig 9.** Difference in percentage of fused auditory images

Fig 10. Difference in slope of lateralization curves

CONCLUSIONS

- Multi-electrode stimulation appears to yield similar results to those obtained in Kan *et al.*, (2013); that is, when ITD=ILD=0, there is a decrease in auditory image fusion, and auditory images are off-center with increasing mismatch. In addition, lateralization with ILDs is more robust to mismatch than with ITDs.
- Activating adjacent electrodes does not appear to improve auditory image fusion, or affect ITD/ILD sensitivity.
- These results suggest that clinical mapping could benefit by considering interaural place-of-stimulation matching to maximize ITD sensitivity, but there is no need to increase spacing between stimulating electrodes in order to improve ITD and ILD perception.

REFERENCES

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

ACKNOWLEDGEMENTS