Effect of Frequency-Place Mapping on Speech Intelligibility: Implications for a Cochlear Implant Localization Strategy

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CIAP 2007

Conference on Implantable Auditory Prostheses

Granlibakken Conference Center

Lake Tahoe, CA

INTRODUCTION

Sound localization is mostly performed by two sets of cues: interaural cues (time and level differences) for the horizontal plane and spectral cues (peaks and notches) for the vertical plane. The spectral localization cues have higher frequencies (4-16 kHz) than the most important speech information (<4 kHz).

To implement spectral cues in a localization strategy, several problems in cochlear implants (CI) must be overcome:

- Much poorer frequency resolution (12-20 channels in the best cases)
- Limited frequency range (upper frequency boundary ~10 kHz)
- Reduced sensitivity to spectral peaks and notches (see Poster D30)

Implementation of a sound localization strategy should not hinder the primary function of a CI, which is to return speech understanding to the deaf or profoundly hearing-impaired. Superimposing spectral peaks and notches on speech may cause a degradation in speech understanding. However, it may be possible to keep the speech information separated from spectral localization information by presenting them to different electrodes.

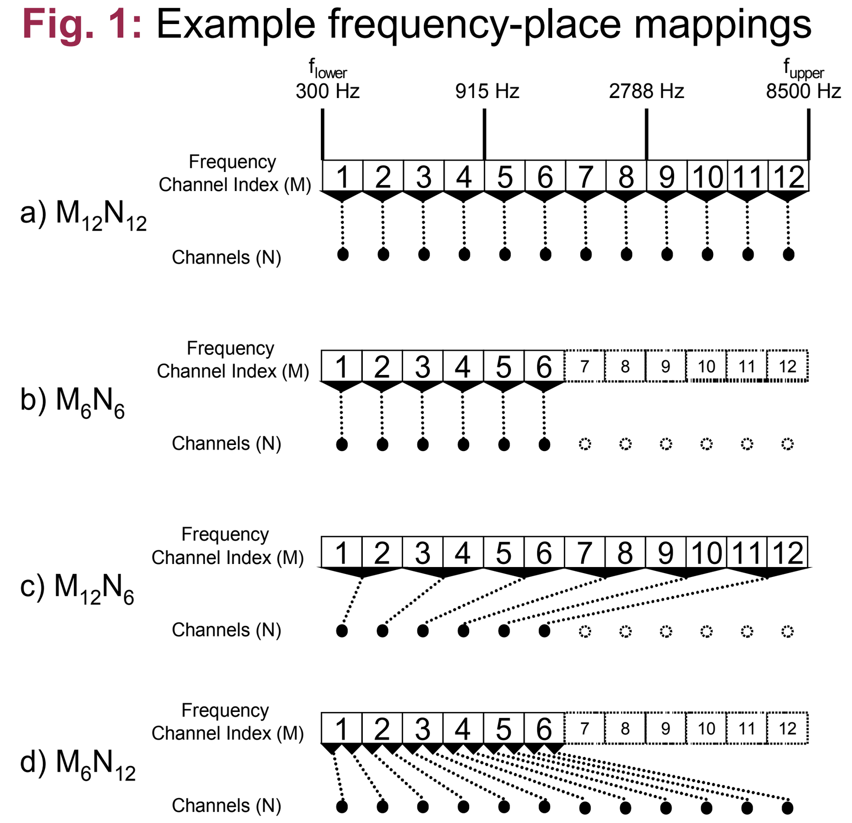
The main purpose of this study is to find if there is EXTRA speech information or EXTRA electrodes used in current CI stimulation strategies. If so, altering the frequency-to-place mapping may allow for the inclusion of spectral cues without hindering speech understanding.

METHODS

1. Processing

- The frequency-to-place mapping was altered by varying the upper frequency boundary (M) while holding the lower frequency boundary fixed at 300 Hz (see Fig. 1). The number of electrodes (N) was covaried.
  - ➢ Upper frequency boundary (M) : 4 = 0.9 kHz, 6 = 1.6 kHz, 8 = 2.7 kHz, 12 = 8.5 kHz, 14 = 16 kHz
  - ➢ Number of electrodes (N) : 4, 6, 8, 10, 12
- 18 conditions tested (see Fig. 2)

Fig. 1: Example frequency-place mappings



2. Subjects

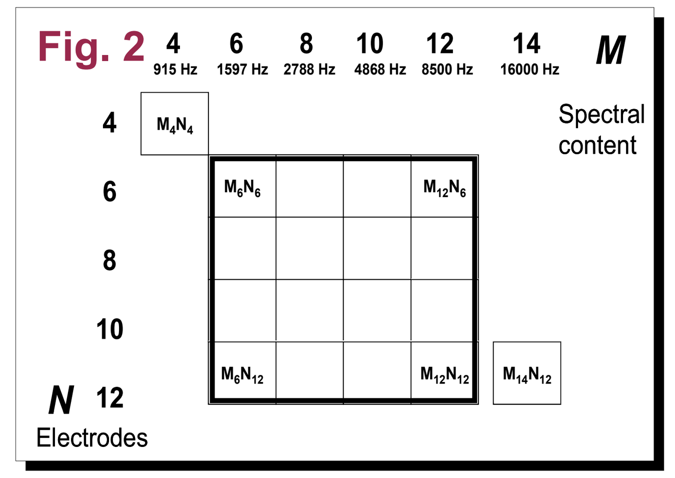
- 7 CI listeners and 6 NH listeners using a CI simulation

3. Conditions

- Four SNRs: quiet, +10 dB, +5 dB, and 0 dB

4. Procedure

- OLSA Sentences: 5 word German nonsense sentences (name, verb, number, adjective, object)
- 90 sentence blocks
  - ➢ 10 warm-up in quiet
  - ➢ 20 × 4 SNRs = 80
  - ➢ Random order



RESULTS

1. Matched Conditions (M = N): Fig. 3

- Saturation in performance with increasing N (p = 0.05 level)
  - ➢ High-performance CIs: N = 8 all SNRs (upper left panel Fig. 3)
  - ➢ Low-performance CIs: performance variable (bottom panels Fig. 3)
  - ➢ NHs: N = 8 in quiet, N = 10 for 10, 5, 0 dB SNRs (upper-right panel Fig. 3)
- Eight channels agrees with Garnham et al. (2002) that holds both upper and lower frequency boundaries fixed and Baskent and Shannon (2005) that holds the upper frequency boundary fixed. Thus, number of necessary channels seems independent of type of spectral manipulation.
- NH data corresponds well with speech intelligibility index (SII)

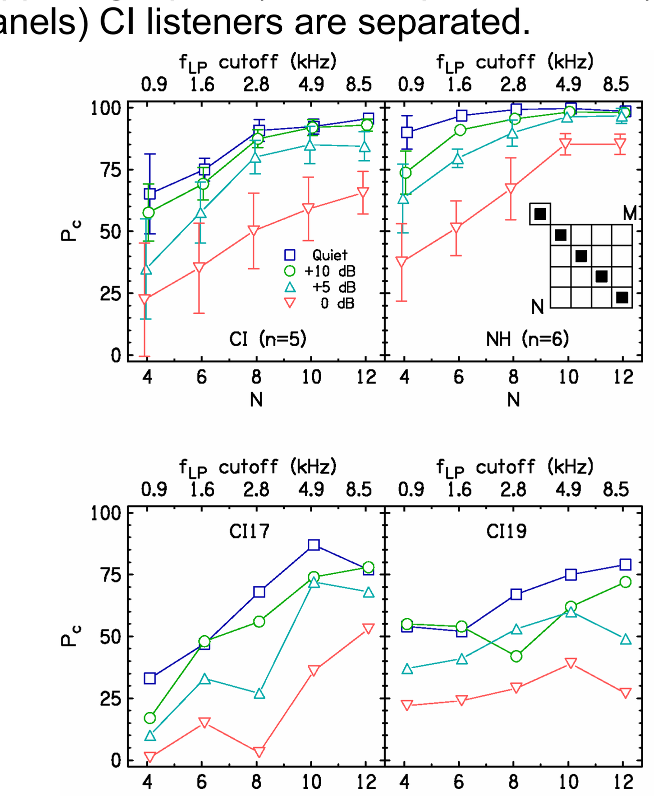
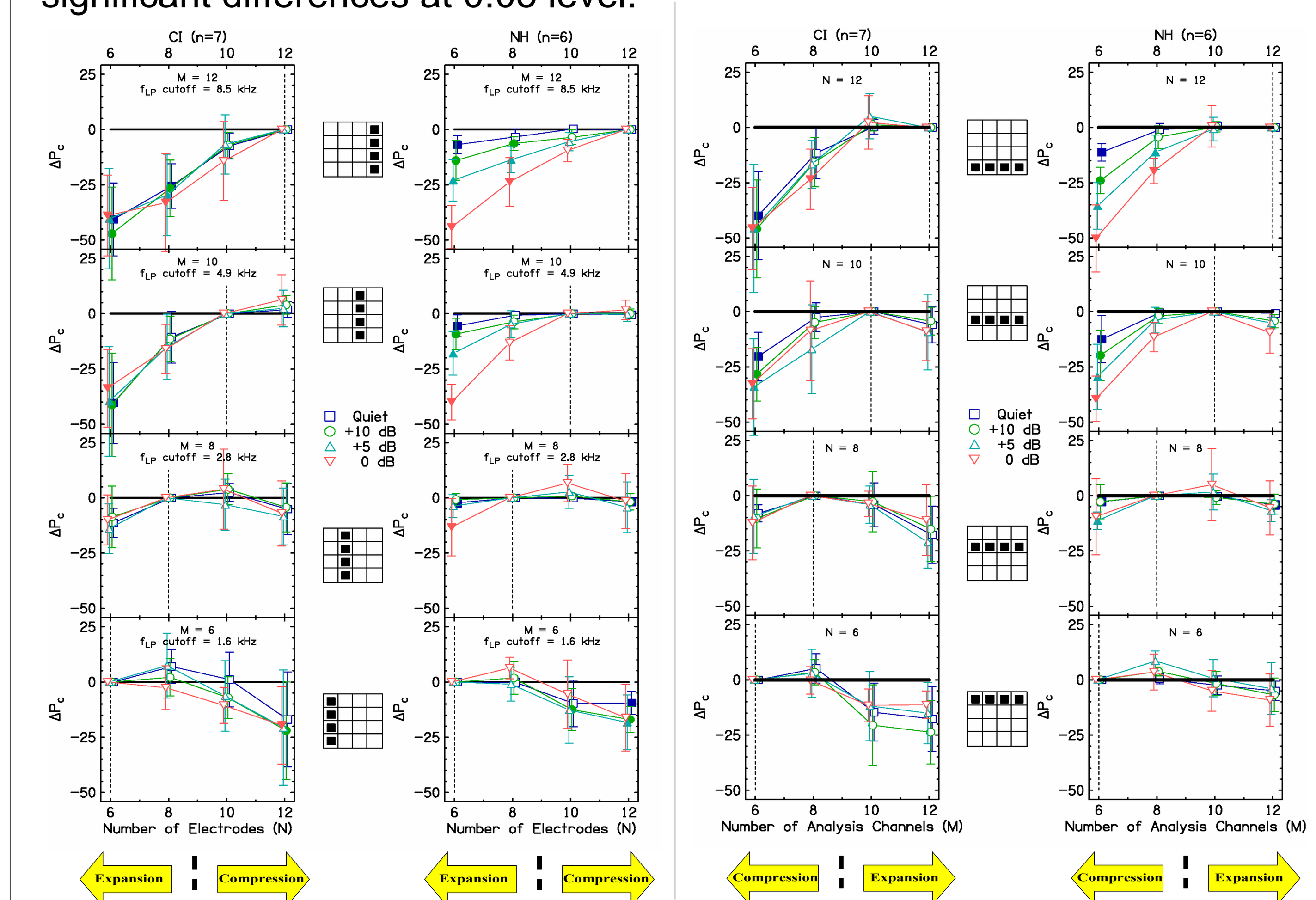


Fig. 3: Matched data (M = N). High-performance (upper-right panel) and low-performance (lower panels) CI listeners are separated.

2. Unmatched Conditions (M ≠ N): Fig. 4

- Significant decreases are seen for conditions greater than ± 2 N (electrodes) from the matched case (with 2 exceptions for NH listeners).
- Significant decreases are seen for conditions greater than ± 2 M from the matched case (with 2 exceptions for NH listeners). This corresponds to a shift of ±0.77 octaves of the most basal electrode and a decreasing shift towards the most apical electrode. This shift is greater than other studies that do not hold the lower frequency boundary fixed (e.g. Baskent and Shannon, 2004)
- NH data show interaction between SNR and the dependent variable. This may indicate a ceiling effect. CI data does not show this interaction.
- There is an asymmetric decrease in ΔP_c. Removing spectral content or electrodes is more detrimental than adding spectral content or electrodes.
- Conditions not different from baseline ($M_{12}N_{12}$):
  - ➢ $M_{10}N_{12}$, $M_{12}N_{10}$, $M_{10}N_{10}$, M_8N_8 ($M_{10}N_8$ for just CIs)

Fig. 4: Unmatched conditions: The left figure is for fixed spectral content (M) and the right figure is for a fixed number of channels (N). P_c is relative to matched conditions in Fig. 3 (shown by dotted line). Filled symbols show significant differences at 0.05 level.



3. Extended frequency range ($M_{14}N_{12}$)

- This condition contains frequencies up to 16 kHz, important for localization cues
- Significant decreases for CIs, not NHs. Reason for decrease in CIs? (Insert your explanation here.)
- Octave shift for most basal electrode is -0.88 octaves, just greater than -0.77 octaves shown to not give significant decreases for other unmatched conditions
- For CI listeners, frequencies up to 14.5 kHz could be used, which yields spectral shifts of not more than 0.77 octaves

Table 1: **Results** for extended frequency range conditions.

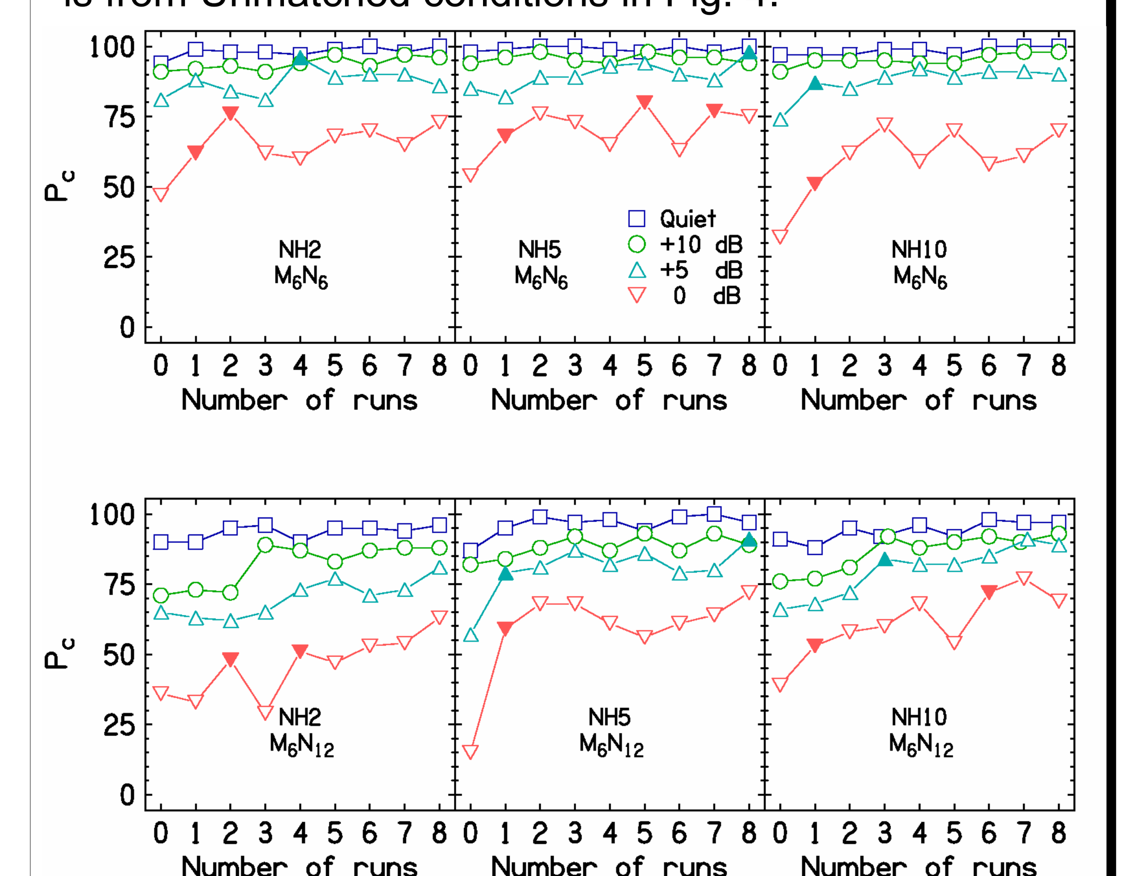
CI	$M_{12}N_{12}$		$M_{14}N_{12}$			
SNR (dB)	Average	Stand. Dev.	Average	Stand. Dev.	Difference	p-value
Quiet	90.57	8.79	79.29	13.50	11.29	**0.047***
+10	87.86	9.19	72.14	15.14	15.71	**0.020***
+5	76.86	15.94	61.86	22.14	15.00	0.087
0	56.86	16.22	36.43	26.44	20.43	0.056

NH	$M_{12}N_{12}$		$M_{14}N_{12}$			
SNR (dB)	Average	Stand. Dev.	Average	Stand. Dev.	Difference	p-value
Quiet	98.50	1.76	98.67	1.03	-0.17	0.846
+10	98.00	1.55	97.83	1.17	0.17	0.838
+5	96.67	3.01	95.17	4.45	1.50	0.511
0	85.33	4.08	88.33	3.98	-3.00	0.227

4. Training and Learning Experiment

- Feedback training was provided with subsequent testing of chosen conditions
- Most significant increases seen in first 1-2 sessions
- No significant difference from matched vs. unmatched learning (ANOVA interaction)
  - ➢ 0 dB: p = 0.58 and +5 dB: p = 0.78
  - ➢ +10 dB and quiet: not analyzed because of ceiling effect

Fig. 5: Learning experiment results for 3 NHs over 8 sessions. Solid points show significant increases. Run 0 is from Unmatched conditions in Fig. 4.



CONCLUSIONS

1. Only 8 electrodes needed for maximum speech understanding

2. Slight changes in frequency-place mapping doesn't cause significant decreases

- ±2 electrodes or ±0.77 octaves (when lower-frequency boundary is fixed)
- 5-6 of 18 conditions yield baseline speech understanding scores

3. These results seem promising for some electrodes can be used as "speech electrodes" and the others as "spatial electrodes" in a CI sound localization strategy. This will be very important if there is an interaction between spectral cues and speech understanding.

REFERENCES

1. Garnham, C., O'Driscoll, M., Ramsden, R., and Saeed, S. (2002). "Speech understanding in noise with a Med-El COMBI 40+ cochlear implant using reduced channel sets," Ear Hear. 23, 540-552.
2. Baskent, D., and Shannon, R. V. (2005). "Interactions between cochlear implant electrode insertion depth and frequency-to-place mapping," J. Acoust. Soc. Am. 117, 1405-1416.
3. Baskent, D., and Shannon, R. V. (2004). "Frequency-to-place compression and expansion in cochlear implant listeners," J. Acoust. Soc. Am. 116, 3130-3140.

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We thank Mr. M. Mihocic for running experiments.
We also thank the CI listeners for their enthusiastic participation in this study.
The equipment for direct electrical stimulation was provided by MED-EL Corp.
This research was supported by the Austrian Science Fund (Project P18401-B15) and the Austrian Academy of Sciences.