VOWEL IDENTIFICATION AND VOWEL MASKING PATTERNS IN MULTI-ELECTRODE ELECTRICAL STIMULATION

Bernhard Laback[1], Werner A. Deutsch[1], W. D. Baumgartner[2], J. S. Hamzavi[2]

[1] Acoustics Research Institute, Austrian Academy of Sciences; [2] ENT-Department, Vienna University Hospital

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Overview

Patients wearing multichannel cochlear implants (CIs) exhibit la rge variability in vowel identification. Channel interactions (as a consequence of spread of electrical fields) are believed t o disrupt the "internal" spectral patterns. For non-simultaneous stimulation strategies, these interactions are rest ricted to so-called neural-population interactions, that result from multiple stimulation of individual neurons (**Fig. 1**). This paper presents measurements of internal representations of steady-state vowels, processed through a CIS-processor, stimulating in monopolar configuration. Vowel masking patterns (VMPs) are measured, representing „neural spectra", which include the channel interactions effects. VMPs of lowly and highly confused vowel pairs are analyzed to find the spectral cu es relevant for identification.

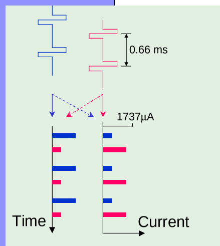


Fig. 1. Neural-population interactions in non-simultaneous stimulation

Design

Subjects and stimulation parameters

-7 postlingually deafened adults supported either with 8 or 12 ch annel CIs by *MedEl* (*Combi 40* and *Combi 40+, respectively*), in monopolar electrode configuration;
-"<u>controlled" clinical settings</u>: CIS-strategy; 1515 pps; logarithmic compression (c=500); staggered electrode stimulation; "Innsbruck Mode"
-calibration of input signal level

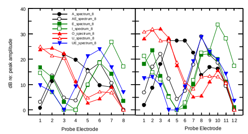


Fig. 2. 8-channel (left) and 12-channel vowel spectra

Vowel identification

- Additive synthesized steady-state german vowels <A, AE, E, I, O, OE, U, UE> (F0 = 100 Hz)
8 or 12 sine-phase sinusoids at CI-filterbank center frequencies, fitting into dynamic range of the input filterbank (**Fig. 2**)
-Digital synthesis and stimulus control via custom made macro rou tines (ST^X-software package)
-Signal transmission: auxiliary input of processor
- 8x8-confusion matrices ⇒ 28 * 2x2 submatrices ⇒ *relative transmitted information RTI* (Miller and Nicely, 1955)
- Selection of vowel pair with smallest *RTI* and additional 1-2 vowels showing highest *RTI* with both pair members
Fig. 3 and 4 (right side) give percent correct scores for the selected vowel s of each subject

Vowel Masking Patterns

- Measurement of vowel masking patterns for selected vowel masker s (900 ms), consisting of masked thresholds for sinusoidal probes (100 ms) temporally centered within the maskers, at center frequencies of processor-filterbank
-Modified Békésy-tracking; minimum of 9 reversals, threshold calculation over las t 6 reversals (standard deviation rule: < 2.5 dB, acoustically)
⇒ Average deviation between 1st and 2nd measurement: 1.9 dB (acous tically)

<u>Derivation of vowel masking patterns from dB-threshold values</u>
- Loudness equalization at half comfortable loudness across elect rode array (according to Lim et al., 1989).
- Calculation of masked thresholds in µA from acoustical masked thresholds by software-simulation of CI-processor, applying individual subject's settings; checking with oscilloscope via detectorbox (*MedEl*, 6.8 kΩ).
- Loudness normalization to account for differences between maske d and unmasked thresholds across probe electrodes i (*in dB µA*):
$VMP_i = (Masked\_Threshold_i - Threshold\_in\_quiet_i) * Loudness\_Correction\_Factor_i$

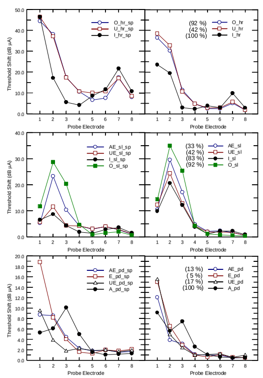
Fig. 3 right: VMPs of 3 subjects with 8-channel CIs, **Fig. 4 right:** VMPs of 4 subjects with 12-channel CIs.
Fig. 3 and 4 left: Amplitude distributions across electrode array of corresponding vowels (subsequently called *electrode spectrum*), calculated considering the individual subject's electrode dynamic ranges and loudness-correction factors

VMP Features

⇒ In general, high similarity between VMPs of highly confused vow els and pronounced differences between VMP-shapes of accurately discriminated vowels.

Measures applied to each possible pair of VMPs for each subject:
• Logarithm of *Euclidean Distance* (corrected for overal level differences); compares vertical aspects of two spectra
• Logarithm of Klatt's (1982) *Weighted Slope Metric* (sums the slope-differences between two spectra, giving greater weight to points near spectral peaks); emphasis on formant peak locations

⇒ Significant correlations between Euclidean Distance and *RTI* (r= 0.59, p < 0.001) and Weighted Slope Metric and *RTI* (r= 0.6, p < 0.001): **Fig. 5**, upper and lower panel, respectively.

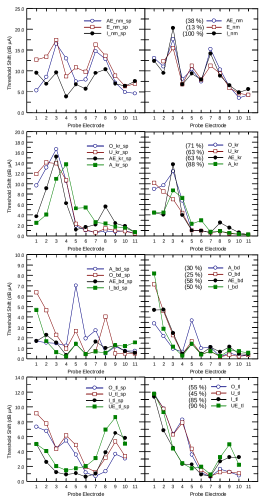


I / O	0.98
I / U	0.80
O / U	0.54

AE / I	0.71
AE / O	0.73
AE / UE	0.46
I / O	0.93
I / UE	0.75
O / UE	0.77

A / AE	0.63
A / E	0.55
A / UE	0.66
AE / E	0.12
AE / UE	0.13
E / UE	0.13

Fig. 3. Electrode spectra (left side) and Vowel Masking Patterns (VMPs) for three 8-channel implantees (right side). Open symbols: pairs with lowest RTI; filled symbols: vowels showing highest RTI with both pair members. The tables give the RTIs of all possible vowel pair combinations



AE / E	0.22
AE / I	0.78
E / I	0.63

A / AE	0.85
A / O	0.84
A / U	0.85
AE / O	0.78
AE / U	0.75
O / U	0.55

A / AE	0.60
A / I	0.57
A / O	0.27
AE / I	0.66
AE / O	0.58
I / O	0.54

I / O	0.81
I / U	0.77
I / UE	0.91
O / U	0.41
O / UE	0.83
U / UE	0.76

Fig. 4. As Fig. 3, for four 12-channel implantees (right side).

⇒ VMPs of some highly discriminated vowel pairs exhibit identical formant peak positions and differ solely in between-peaks characteristics.

Two spectral contrast measures for further analysis of vertical spectral aspects:
- Euclidean Distance of second derivatives across spectral points (emphasis on fine-structure spectral contrasts, e. g. small peaks)
- Difference between RMS of spectral maxima and minima (averaged peak-valley-contrast)

⇒ Higher correlation between fine structure contrasts and *RTI* (r = 0.59 , p < 0.001) than between *peak-valley-contrasts* and RTI (r = 0.41, p < 0.01) indicates stronger importance of differences in fine-structure contrasts than in overal spectral contrast.

<u>Comparison: electrode spectra / VMPs (**Fig. 3 and 4**, left/right side, respectively)</u>

⇒ Similar overal spectral contrasts (no compression) and formant peak positions in electrode spectra and VMPs (several characteristic formant peak differences between vowel pairs already absent in electrode spectra).

⇒ For highly confused vowels, the fine structure spectral contras ts found in the electrode spectra are reduced in VMPs, likely due to neural-population interactions.

⇒ The relatively high importance of vertical spectral aspects is in contrast to studies with normal hearing (Klatt, 1982) or hearing impaired subjects (van T asell et al., 1987, Turner and Henn, 1989), in which formant positions were most imp ortant. This may be explained by deteriorated formant-position cues due to the small number of channels.

Conclusions

- VMPs are good predictors for the identification of steady-state vowels in CIS-based monopolar CI-stimulation.
- VMPs indicate similar relevance of vertical spectral aspects (fi ne structure spectral contrasts) and horizontal spectral aspects (formant locations) f or vowel identification.
- CI-signal processing (filterbank, dynamic range distribution across electrode array, amplitude compression) causes smearing of characteristic differe nces in formant locations between vowels, increasing the relative importance of fine structure spectral characteristics.
- Neural-population interactions seem to smear primarily fine-structure spectral characteristics, causing confusions between vowels with similar overal spectral contours.

<u>Suggestions for future processing strategies</u>

- Enhanced transmission of between-peak fine structure may pronounce charateristic spectral details and also improve formant positions estimation; the minimum formant height (peak-to-valley-difference) should be determined by the degree of channel - interaction.
- Peak-picking strategies (e. g. *n-of-m* or *SPEAK*) may be contra-productive, at least for implants with relatively small channel numbers.

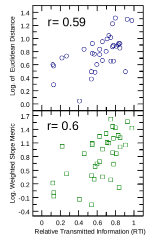


Fig. 5. Euclidean Distance (upper) and Weighted Slope Metric (lower) versus RTI

References

Lim, H. H., Tong, Y. C., and Clark, G. M. (1989). "Forward masking patterns produced by intracochlear stimulation of one and two electrode pairs in the human cochlea", J. Acoust. Soc. Am. 86, 971-980.
Klatt, D. H. (1982). "Prediction of perceived phonetic distance from critical-band spectra: A first step", Proc. IEEE Int. Conf. Speech Acoust. Signal Process. 129,1278-1281.
Miller, G., and Nicely, P. (1955). "An analysis of perceptual confusions among some English consonants," J. Acoust. Soc. Am. 27, 338-352.
Van Tasell, D. J., Fabry, D. A., and Thibodeau, L. M. (1987). "Vowel identification and vowel masking patterns of hearing-impaired subjects," J. Acoust. Soc. Am. 81, 1586-1597.

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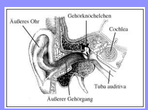

<u>Contact</u>: Bernhard Laback, Acoustics Research Institute, Austrian Academ y of Sciences, Liebigg. 5, A-1010-Wien, Austria, Bernhard.Laback@oeaw.ac.at http:// www.kfs.oeaw.ac.at