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# Channel interaction and speech processing strategies for cochlear implants

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**Work supported by NIH-NIDCD**

## Abstract

A limitation of multichannel cochlear implants is that electrical channel interactions can arise when multiple electrodes are stimulated simultaneously. Channel interaction can be reduced by decreasing current levels delivered to each electrode, through improved electrode positioning and design, or by using speech processing strategies that stimulate electrodes sequentially. The goal of the present study was to examine the relationship between channel interaction and speech recognition for several speech strategies varying in the number of electrodes stimulated simultaneously. Based on previous research, susceptibility to channel interaction is expected to vary as a function of electrode configuration. Thus patients with strong susceptibility to channel interaction will produce higher speech recognition scores for sequential as opposed to simultaneous speech strategies. Speech strategy performance was evaluated with acute listening trials where patients identified consonants and vowels with each of the following speech strategies, listed in order from sequential stimulation to fully simultaneous stimulation: Continuous Interleaved Sampler (CIS), Paired Pulsatile Sampler (PPS), Hybrid Analog Pulsatile (HAP), and Simultaneous Analog Stimulation (SAS). Preliminary results showed that a greater degree of channel interaction was associated with the highest speech recognition scores for CIS, midrange scores for HAP, and the lowest scores for SAS.


[**Work supported by NIH-NIDCD**]

# Electrode Configurations:

- **Enhanced Bipolar Electrode (ENH)**
  - Diagonal electrode pairs provide a wider electrode separation so that loudness growth can be achieved with bipolar stimulation.
- **ENH+Electrode Positioning System (ENH+EPS)**
  - EPS pushes electrode array towards the modiolus, where the spiral ganglion cell bodies reside
- **High Focus Electrode+EPS (HF+EPS)**
  - Longitudinally-arranged plate electrodes orient the current field toward spiral ganglion cell bodies
  - “dielectric partitions” designed to reduce current spread to adjacent electrodes

# Subjects

| Subject | Age | Electrode Type | Speech Strategy | Duration of HL (yrs) | Duration of Deafness (yrs) | Duration of CI Use (yrs) |
|---|---|---|---|---|---|---|
| DF | 66 | ENH | PPS | 43 | 5 | 2.2 |
| EC | 67 | ENH | CIS | .2 | .2 | 2 |
| VC | 55 | ENH | CIS | 18 | 8 | 2.1 |
| CSM | 57 | ENH+EPS | CIS | 35 | 18 | 1.4 |
| RGL | 46 | ENH+EPS | CIS | .2 | .2 | .4 |
| MI | 47 | ENH+EPS | CIS | 20 | 10 | 1.7 |
| BC | 49 | HF+EPS | CIS | 46? | 2 | .7 |
| ML | 68 | HF+EPS | PPS | 34 | 26 | .4 |
| BD | 57 | HF+EPS | PPS | 39 | 8 | 1.1 |

# Methods and Stimuli: Speech Processing Strategies

| Speech Strategy | Channel Stimulation Order | Number of Simultaneous Channels | Analog or Pulsatile | Bipolar or Monopolar | Stimulation Rate/Channel pulses per sec (pps) |
|---|---|---|---|---|---|
| Continuous Interleaved Sampler (CIS) | Apex to Base: 1, 2, … 7, 8 | 0 | Pulsatile | Monopolar | 833 pps |
| Paired Pulsatile Sampler (PPS) | 1+5, 2+6, 3+7, 4+8 | 2 | Pulsatile | Monopolar | 1600 pps |
| Quadruple Pulsatile Stimulation (QPS) | 1,3,5,and 7; 2,4,6, and 8 | 4 | Pulsatile | Monopolar | 3300 pps |
| Hybrid Analog Pulsatile (HAPs) | 1-5 SAS, 6 and 7 CIS | 5 | Analog and Pulsatile | Monopolar and Bipolar | N/A |
| Simultaneous Analog Stimulation (SAS) | 1-7 simultaneous | 7 | Analog | Bipolar | N/A |

Note: Strategies were developed on the CLARION Research Interface (CRI) platform.

# Methods and Stimuli: Psychophysics

Simultaneous masked thresholds were obtained for the following conditions (**bold** print):

- Pulses are presented either to a single electrode (**PROBE**) or simultaneously to two electrodes (**PROBE+MASKER**)
  - Masker Electrode: 4 (Masker fixed at 70% of its threshold)
  - Probe Electrodes: 1, 2, 3, 5, 6, and 7
- When two electrodes are stimulated simultaneously, they either have the same phase (**IN-PHASE**) or opposite phase (**OUT-OF-PHASE**)
  - **In-Phase**: same phase, overlapping current fields add together
  - **Out-of-Phase**: opposite phase, overlapping current fields cancel
- Each condition was tested with bipolar and monopolar configurations
  - **Monopolar**: broad current field: current applied between medial electrode and headpiece
  - **Bipolar**: narrow current field: current applied between two intracochlear electrodes

# Background: Psychophysics

- As electrode interaction increases, current fields add prior to neural activation
  - "Out-of-Phase" > "Probe Alone" > "In-Phase"

- As interaction decreases, thresholds become phase-independent :
  - "Probe Alone" > "Out-of-Phase" & "In-Phase"="Out-of-Phase"

- The magnitude of electrode interaction can be measured as:
    - **Difference Threshold** = "Out-of-Phase" - "In-Phase"
      - Larger Difference Threshold indicates more interaction
      - Difference Threshold = 0 when no interaction occurs

- The Difference Threshold should approach a value of zero with increasing distance between the masker and probe electrode

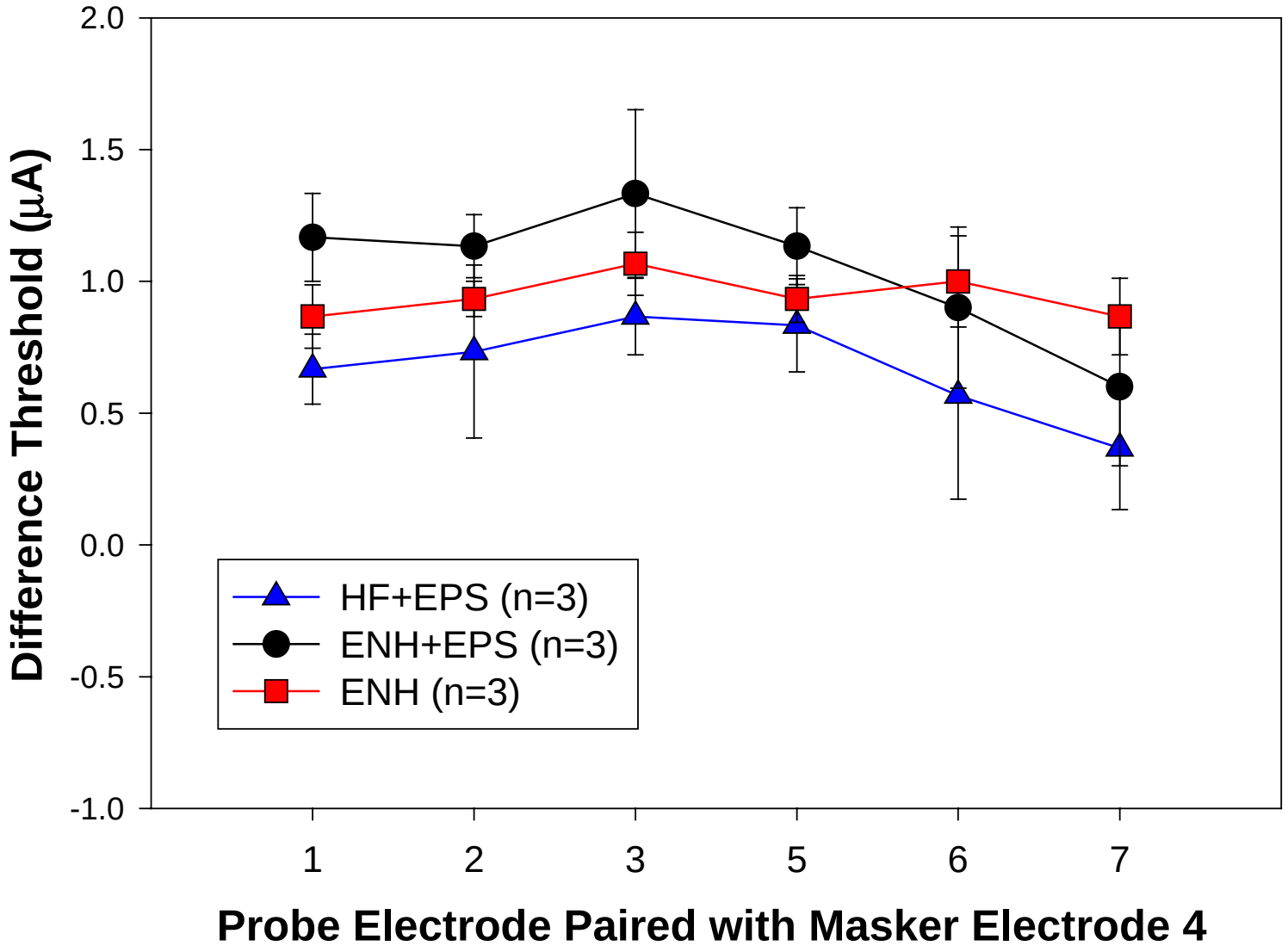
# Results: Pattern of Interaction Spread

- **Normalized Data (Difference Threshold / Probe Alone Threshold)**

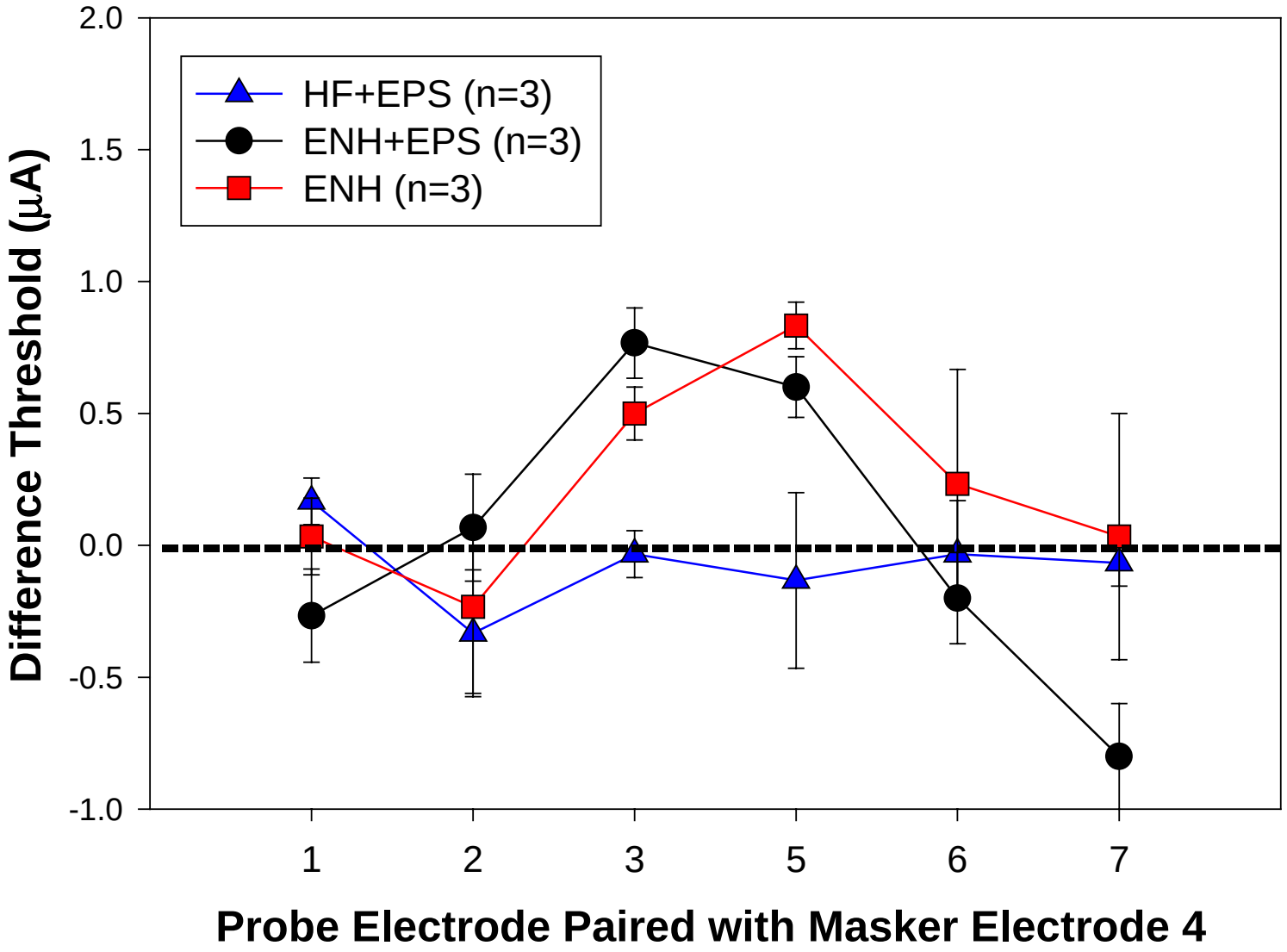
- **Figure 1:** simultaneous **monopolar** stimulation,
  - Channel interaction occurred even for the widest electrode separations, but the magnitude was slightly decreased
  - The HF+EPS group had the lowest levels of interaction

- **Figure 2:** simultaneous **bipolar** stimulation,
  - Interaction decreased with increasing electrode separations.
  - For ENH and ENH+EPS, interaction dropped to negligible levels when the masker, probe separation was by two or more electrodes.
  - For the HF+EPS group, interaction was at negligible levels even with adjacent masker,probe pairs, although there was an increase for the apical-most electrode.

# Figure 1: Monopolar Channel Interaction Spread



# Figure 2: Bipolar Channel Interaction Spread



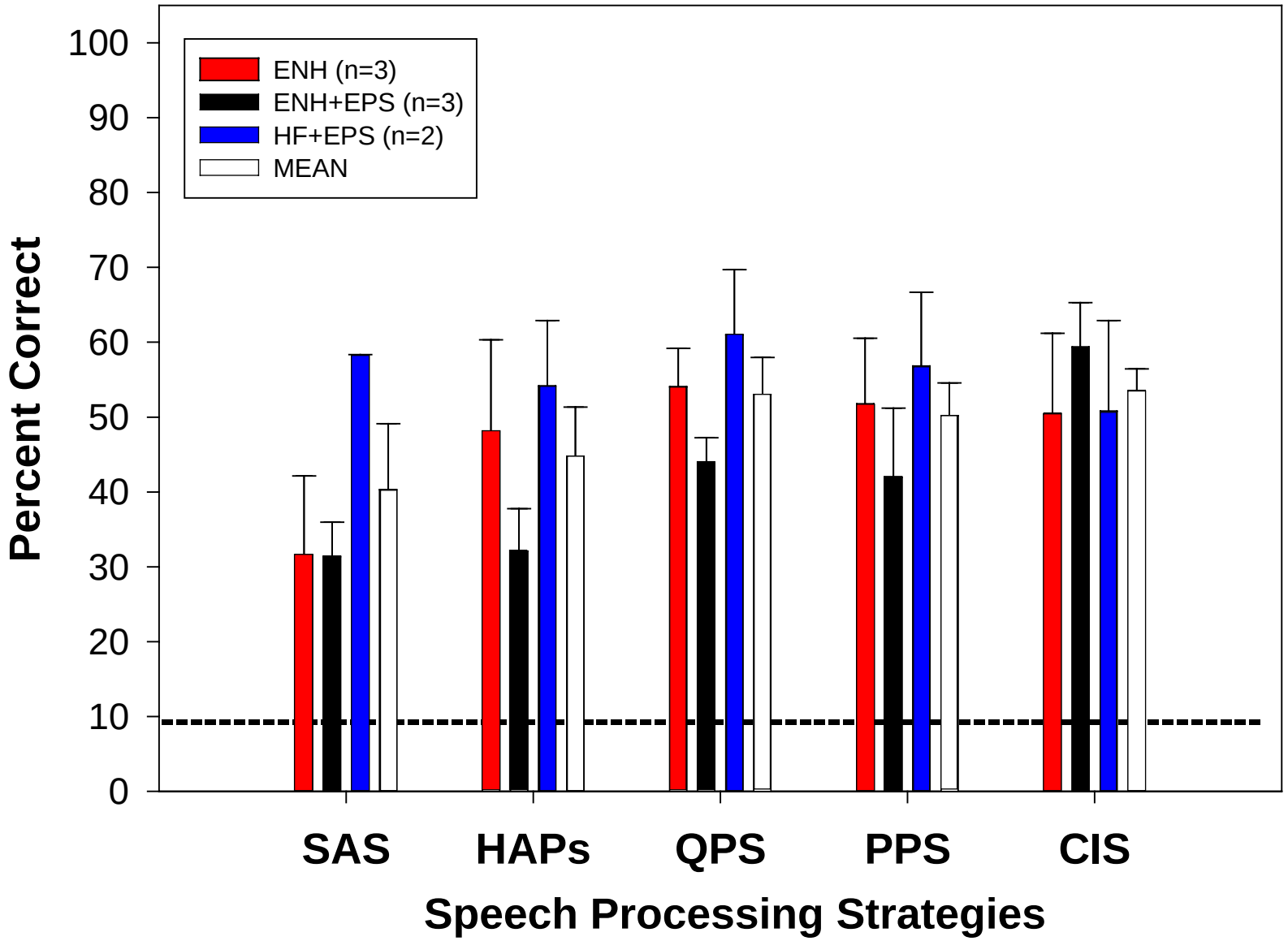
# Results: Speech Processing Strategies x Electrode Configuration

- **Figures 3 - 5:** Results are from acute listening trials with each speech strategy. Speech recognition performance was evaluated using 11 vowels /hVd/, 16 Iowa consonants /aCa/, and 20 H.I.N.T. sentences. Chance performance was 9% for vowels and 6% for consonants (dashed line).

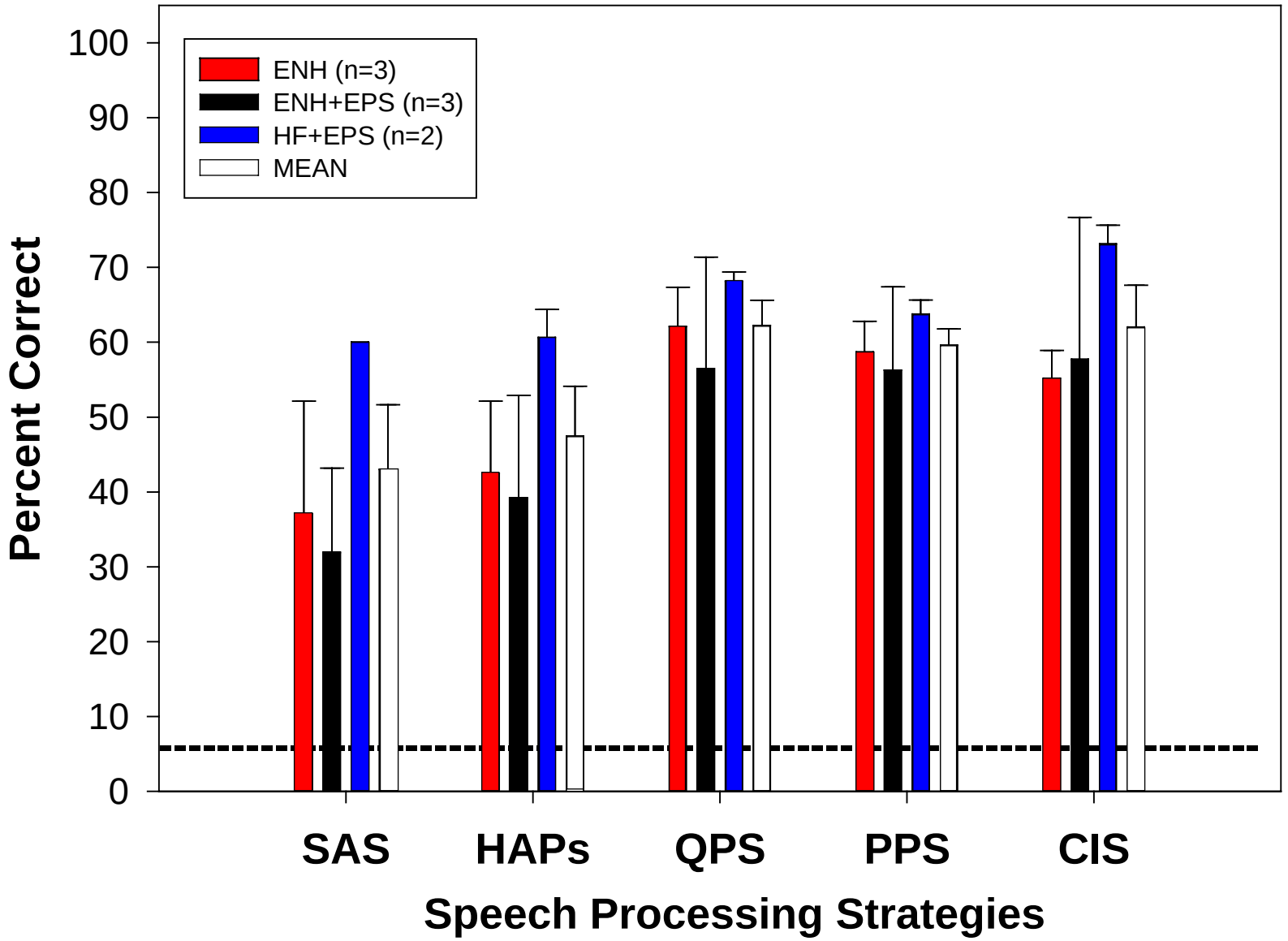
- Performance improved as the number of simultaneous channels decreased (e.g. SAS & HAPs => QPS, PPS, CIS) and appeared to reach a plateau with the stimulation of 4 (i.e. QPS) or fewer simultaneous channels (i.e. PPS and CIS). The performance improvement was most noticeable for the ENH and ENH+EPS groups.

- A marked improvement in speech recognition performance with more simultaneous channels was not evident. However, unfamiliar speech strategies are at a considerable disadvantage with acute listening trials (see QPS), and even a slight improvement may prove to be significantly better over time.

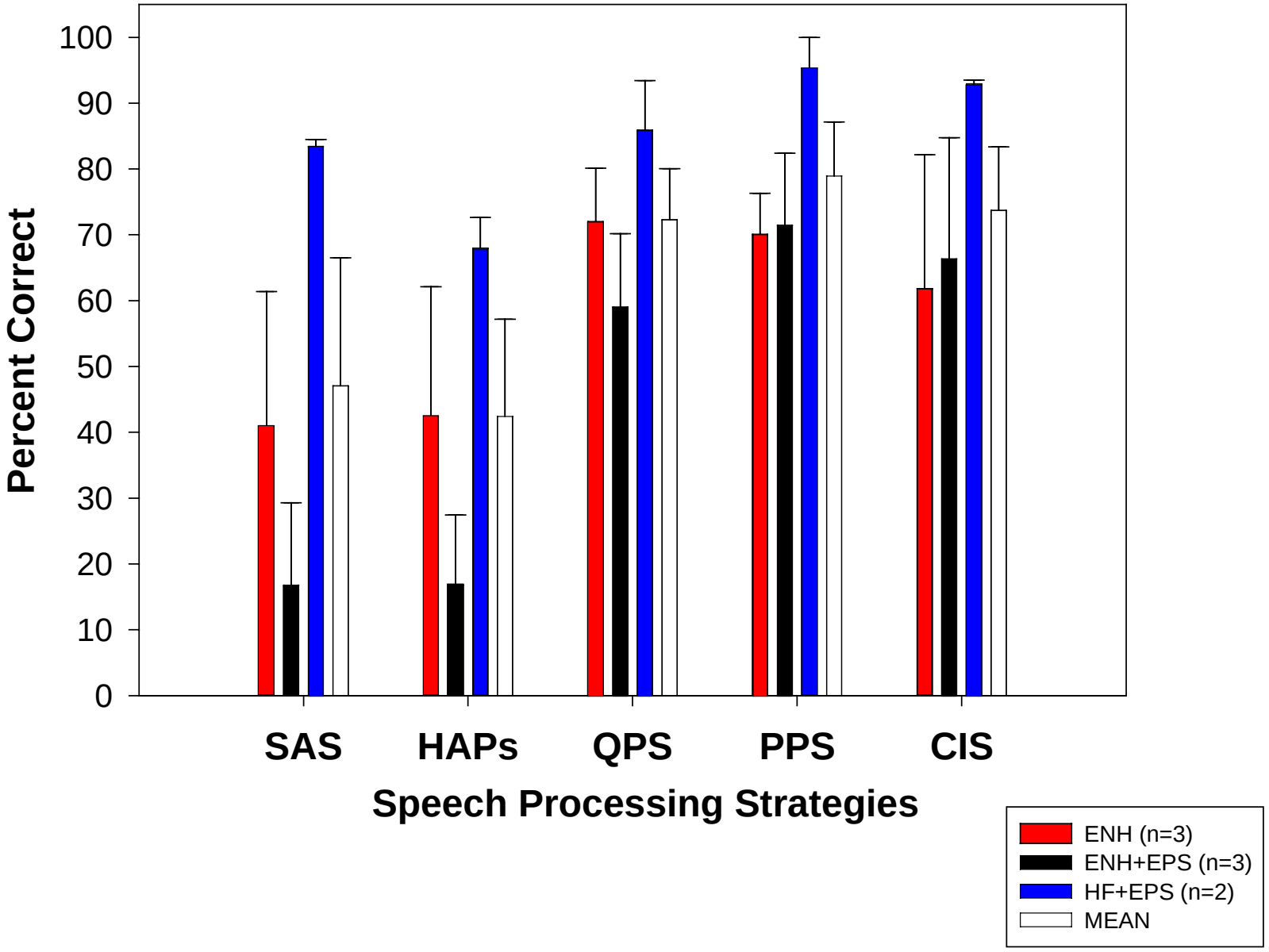
# Figure 3: Vowels /hVd/



# Figure 4: Consonants /aCa/



# Figure 5: Sentences (H.I.N.T.)



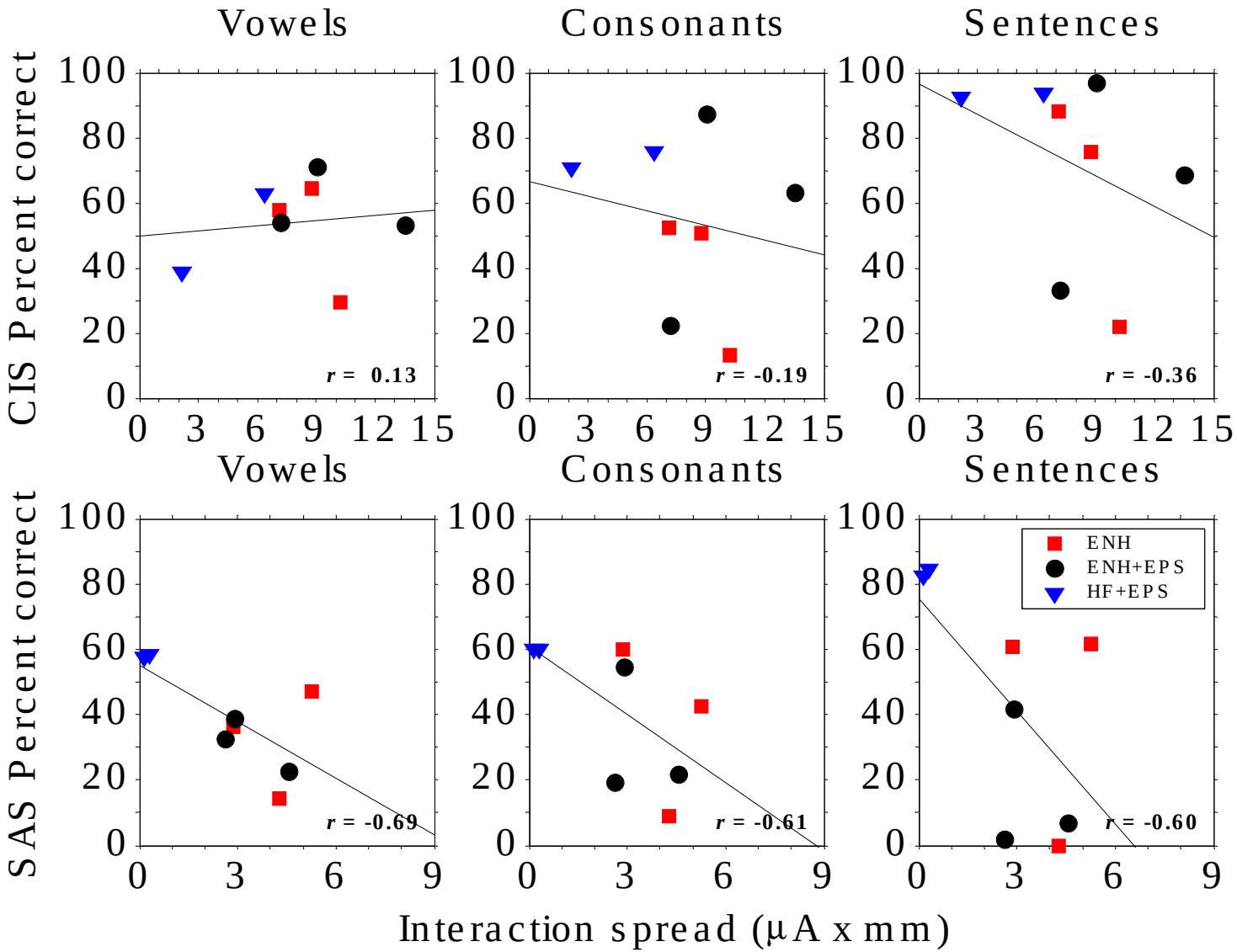
# Results: Speech Processing Strategies x Interaction Spread

- **Figure 6:** The x-axis is the area under the interaction spread curve for each subject (refer to Figs 1 and 2). The y-axis is the percent correct score for the CIS (upper panels) or SAS strategy (lower panels).

- CIS uses monopolar (MP) stimulation and SAS uses bipolar (BP) stimulation. Therefore, CIS speech recognition performance was correlated with MP interaction spread and SAS speech recognition was correlated with BP interaction spread.

- The results show a negative correlation between interaction spread and speech recognition. Since channel interaction is more problematic for simultaneous than sequential stimulation, stronger correlations were found between interaction spread and SAS speech recognition performance than with CIS performance.

# Figure 6: Relationship Between Interaction Spread and Speech Recognition



## Summary and Conclusions

- **Interaction Spread**
  - With simultaneous monopolar stimulation, channel interaction occurred even with the maximum masker, probe separation.
  - With simultaneous bipolar stimulation, channel interaction dropped to negligible levels when the masker and probe electrode were 2 electrodes apart.
- **Speech Processing Strategies**
  - Speech recognition performance improved as the number of simultaneous electrodes was reduced to 4 or less.
  - This performance improvement was more noticeable for the ENH and ENH+EPS groups.

## Summary and Conclusions (cont.)

- **Learning:**
  - Comparisons of speech recognition performance are complicated by using acute listening trials with novel speech processing strategies.

- **Speech Processing Strategies x Interaction Spread**
  - A moderate, negative relationship was found between interaction spread and speech recognition performance for the simultaneous speech processing strategy (i.e.SAS).

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