A parametric study of the CIS strategy

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Outline

- Effect of parametric variations of CIS processors:
  - Pulse rate
  - Pulse width vs. pulse amplitude
  - Signal bandwidth
  - Bandpass filter order
  - Compression function
- Paired-Pulsatile Processors (PPS)
- Virtual-Channel CIS processors
- Average CIS - alternative implementation of CIS

Introduction

- The CIS strategy requires the specification of many parameters, which when properly selected can significantly improve patient's performance (Wilson et al., 1995).
- Knowing the effect of individual CIS parameters on speech performance is extremely important because most of those parameters can easily be changed using the fitting software of commercial implant devices.
- Of great importance is which parameters are most likely to improve patient's performance. In the present study, we will investigate the effect of several CIS parameters on speech performance.

Methods

- **Subjects**
  Six post-lingually deafened adults wearing the Med-El/CIS-link device. All subjects have been wearing their device for more than a year.

- **Speech Material**
  - 11 vowels in /hVd/ context from the Hillenbrand *et al.* (1995) database produced by adults (male and female) and children.
  - 20 consonants in /vCv/ context (v=/i, a, u/) produced by a female speaker (recorded at the House Ear Institute)
  - Monosyllabic words (CNC)

Laboratory Cochlear Implant Processor

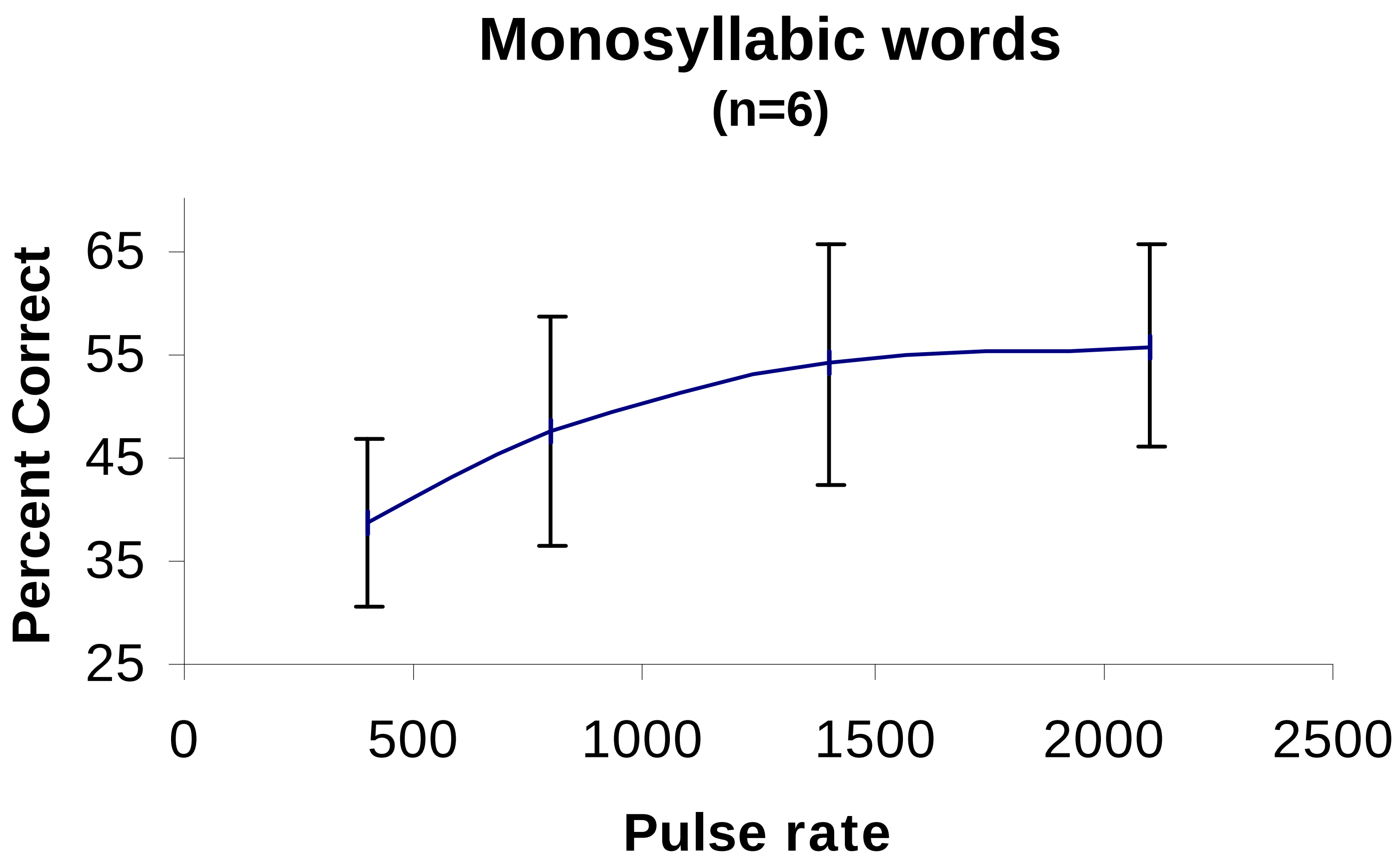
- All CIS variations were implemented and tested on our laboratory processor.
- Based on the Geneva/RTI/MEEI design.
- Extended output circuit to 6 current sources.
- Capable of delivering pulses at a high rate either simultaneously or in an interleaved manner.
- Offers hardware and software flexibility.

Pulse Rate Study

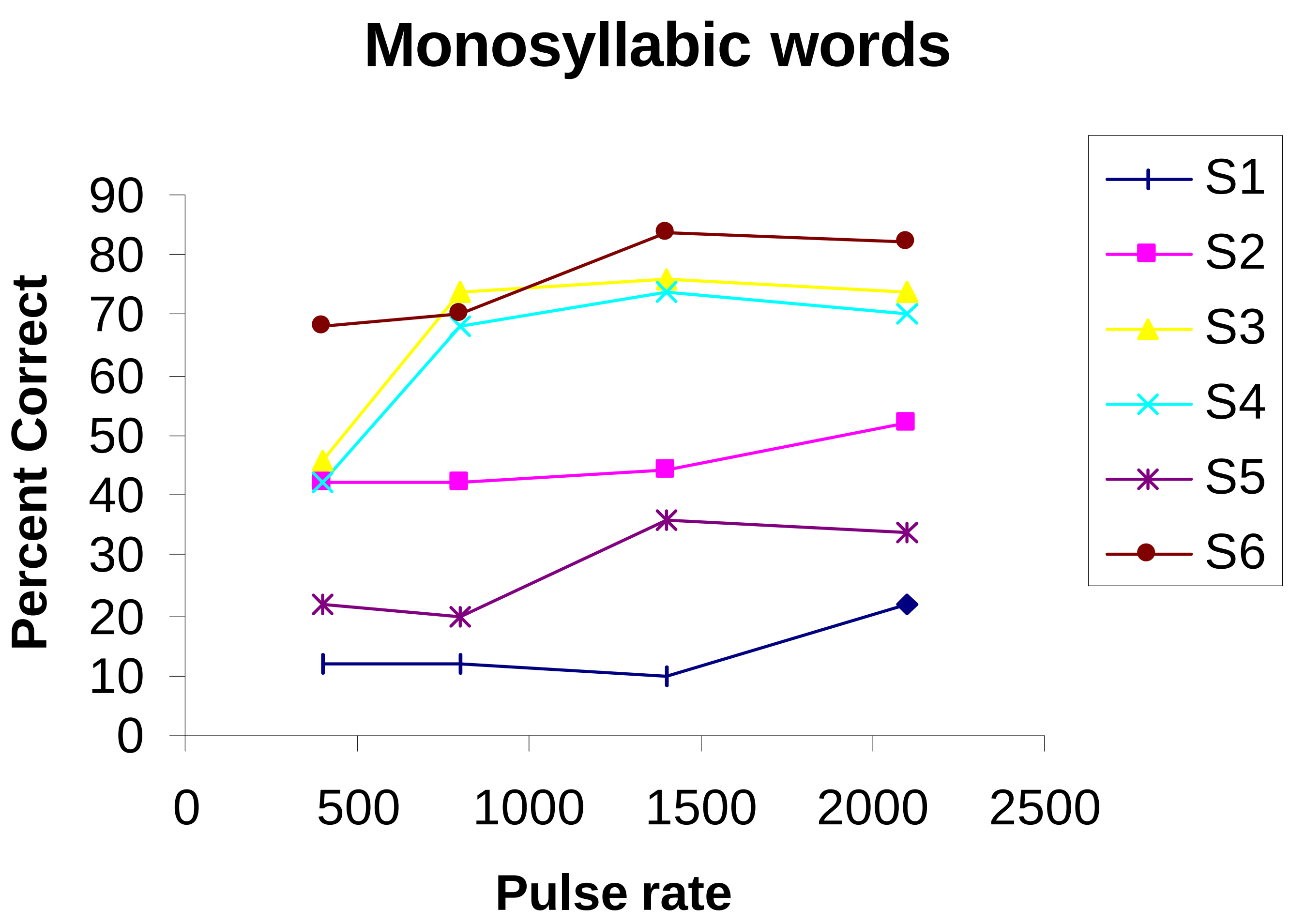
- Pulse rate was varied by varying the temporal gap between pulses.
- Pulse width was <u>fixed</u> at 40 μsec/phase
- Pulse rates: 400, 800, 1400, 2100 pulses/sec
- Low-pass cutoff frequencies (envelope detection):

	Pulse Rate			
	400	800	1400	2100
Cutoff (Hz)	100	200	400	400

Effect of pulse rate on open-set recognition



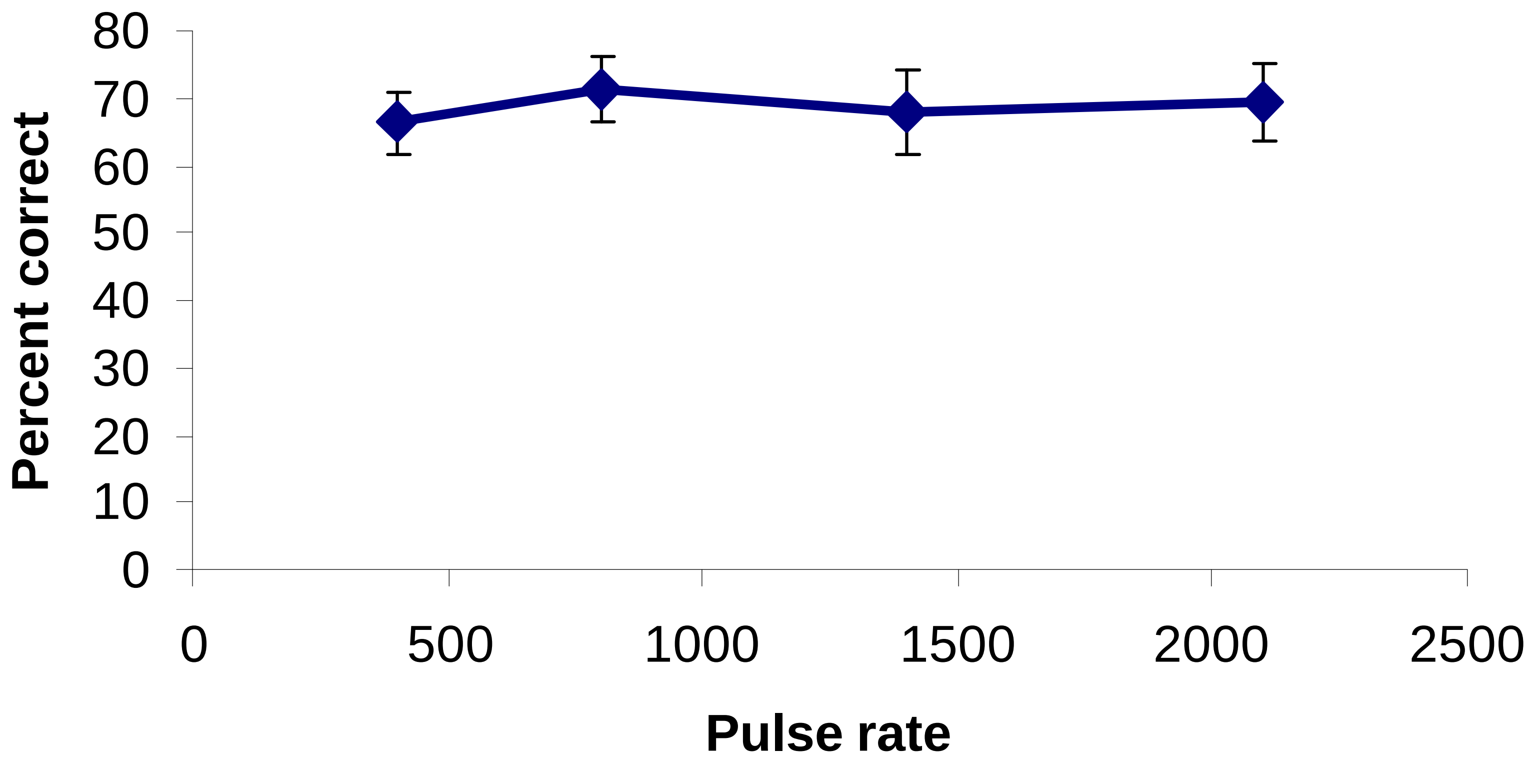
Individual subject's performance



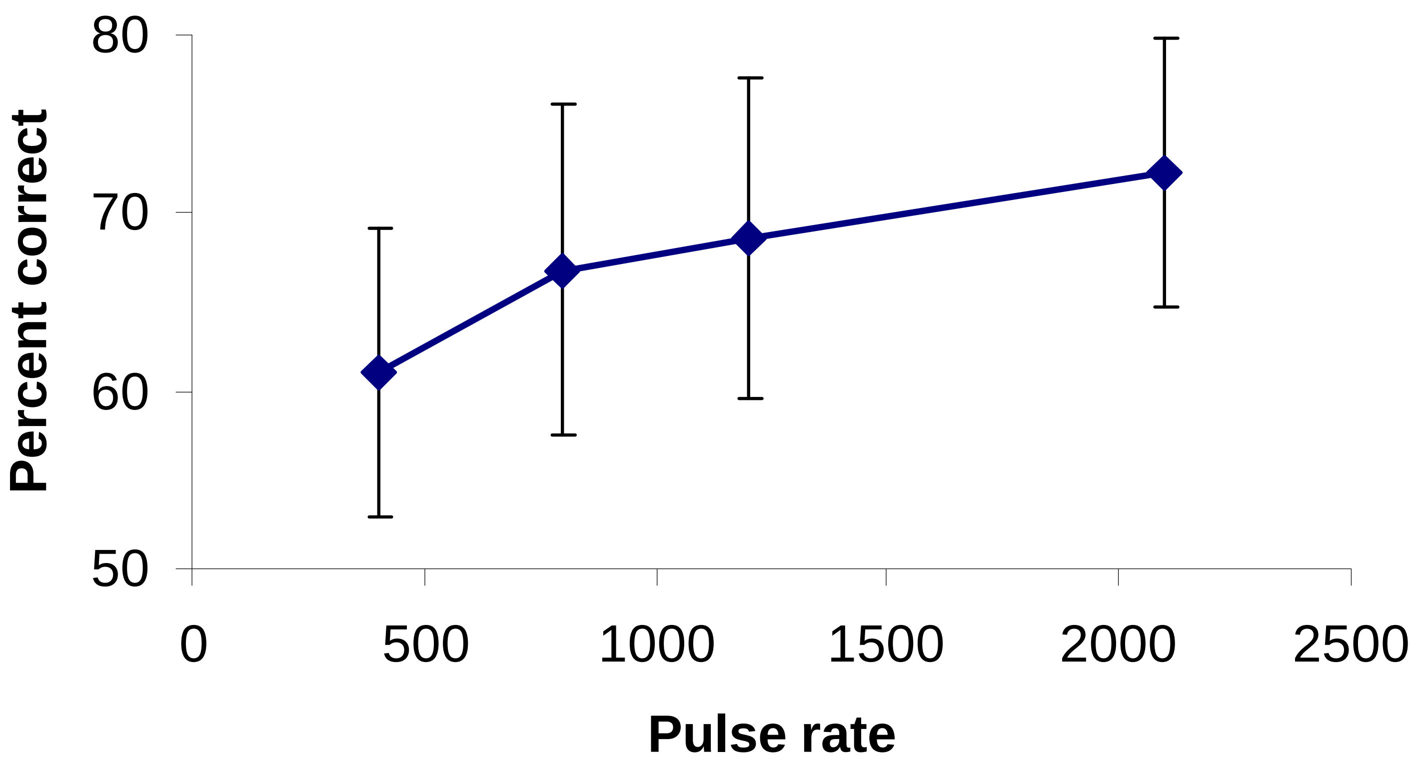
Statistical Analysis

- Repeated measures ANOVA indicated a significant main effect ($F_{3,15}=7.2$, $p<0.005$) of pulse rate.
- *Post-hoc* analysis showed:
  - Mean percent correct score at 2100 pps was significantly ($p=0.01$) greater than the score at 800 pps and the score at 400 pps ($p=0.005$)

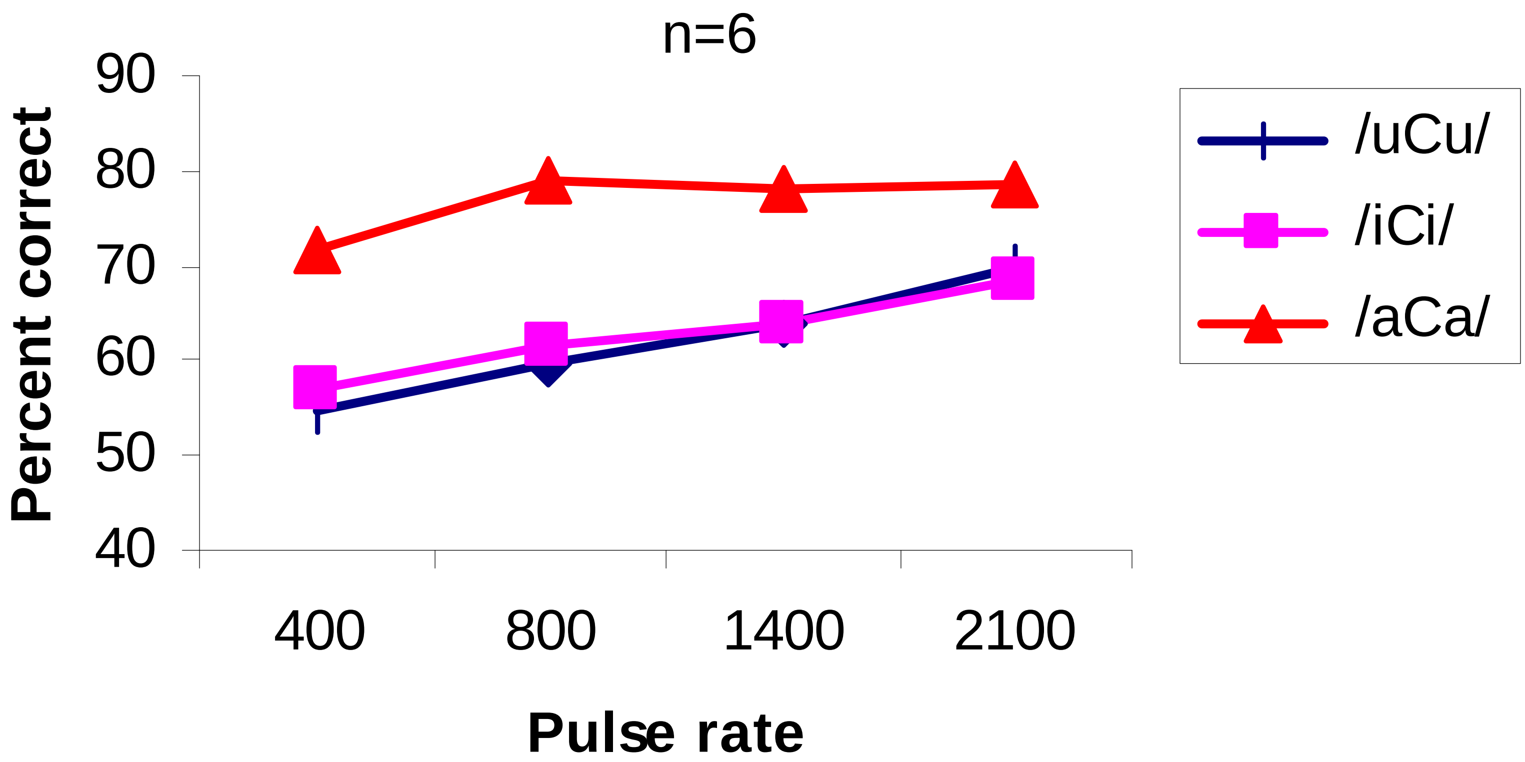
Multi-talker Vowel Recognition



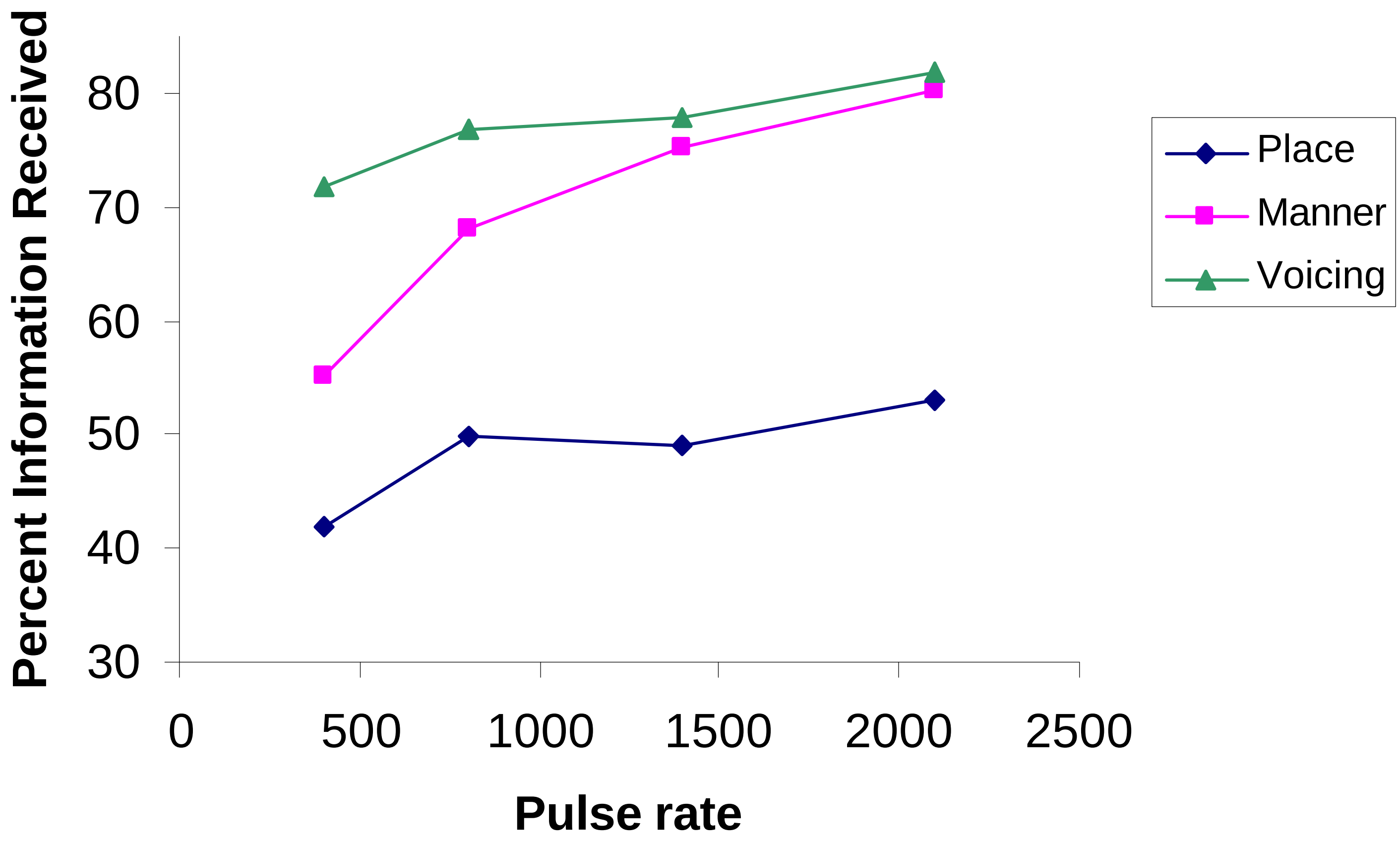
Consonant Recognition



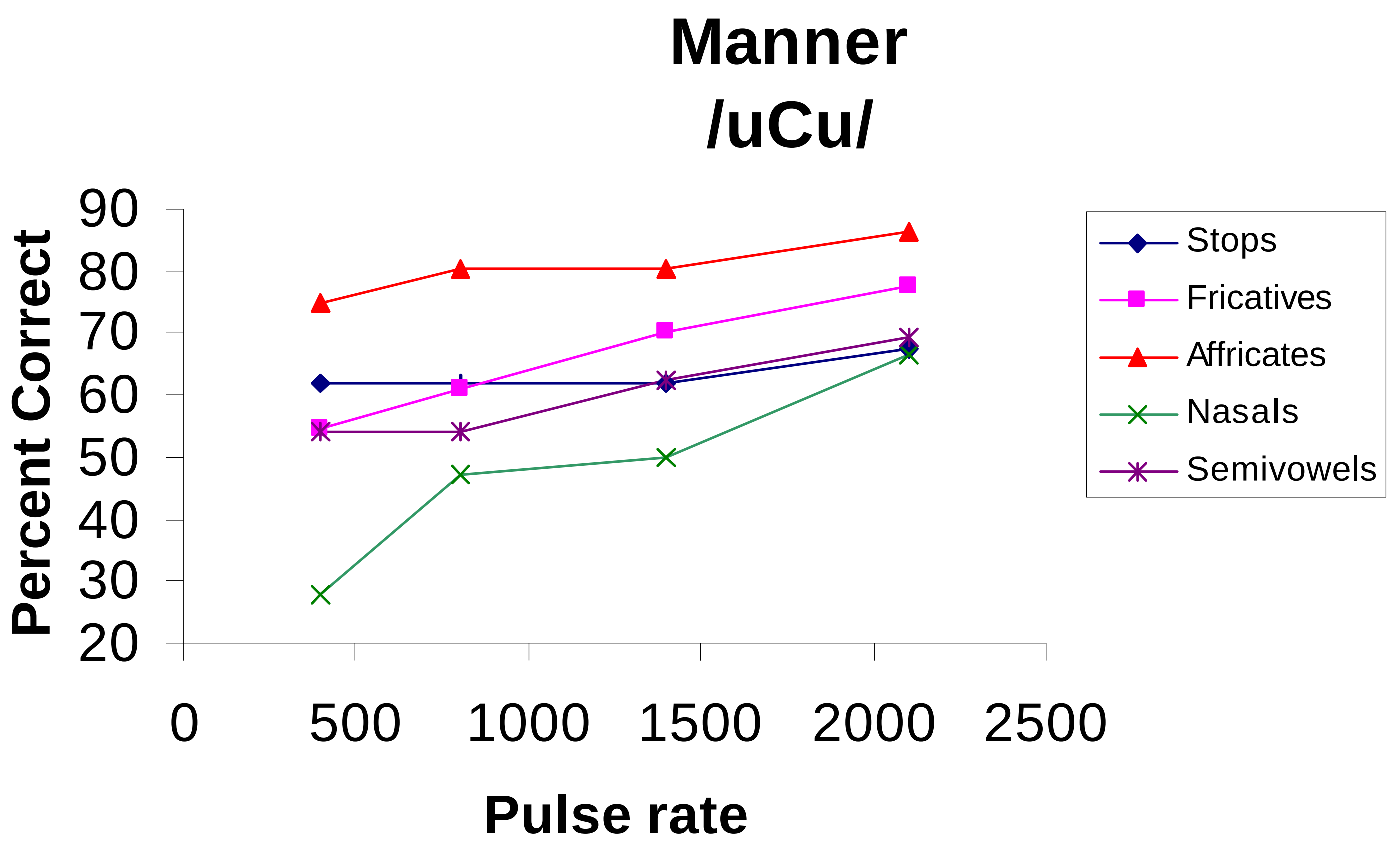
Effect of vowel context



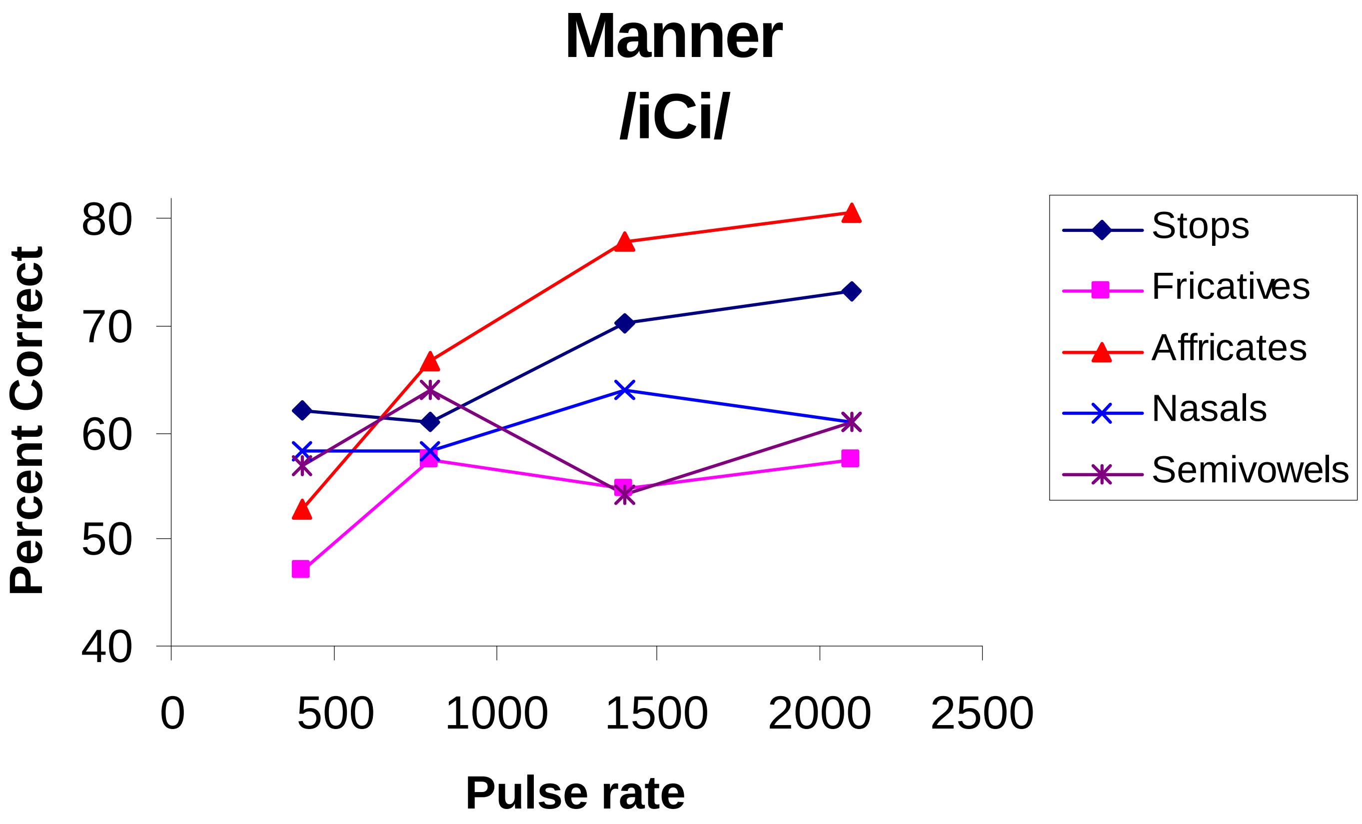
Feature Analysis



Identification of /uCu/ divided by manner



Identification of /iCi/ divided by manner



Statistical Analysis

- ANOVA performed on mean percent correct identification of /vCv/ consonants showed a significant ($p < 0.0001$) main effect of pulse rate.
- *Post-hoc* analysis indicated that the:
  - mean score at 2100 pulses/sec > mean score at 800 pulses/sec ($p=0.05$)
  - mean score at 800 pulses/sec > mean score at 400 pulses/sec ($p=0.02$)

UTD

Discussion

- The effect of pulse rate on consonant recognition seems to be greatly affected by the vowel context.
- High pulse rate does not improve singificantly consonant recognition in the /aCa/ context, but it significantly improves recognition of consonants in the /i,u/ environments.
- Feature analysis indicated a significant increase in manner with higher rates:
  - manner at 2100 pps > manner at 800 pps (p=0.019)
  - manner at 1400 pps > manner at 800 pps (p=0.012)
  - manner asymptotes at 1400 pps.

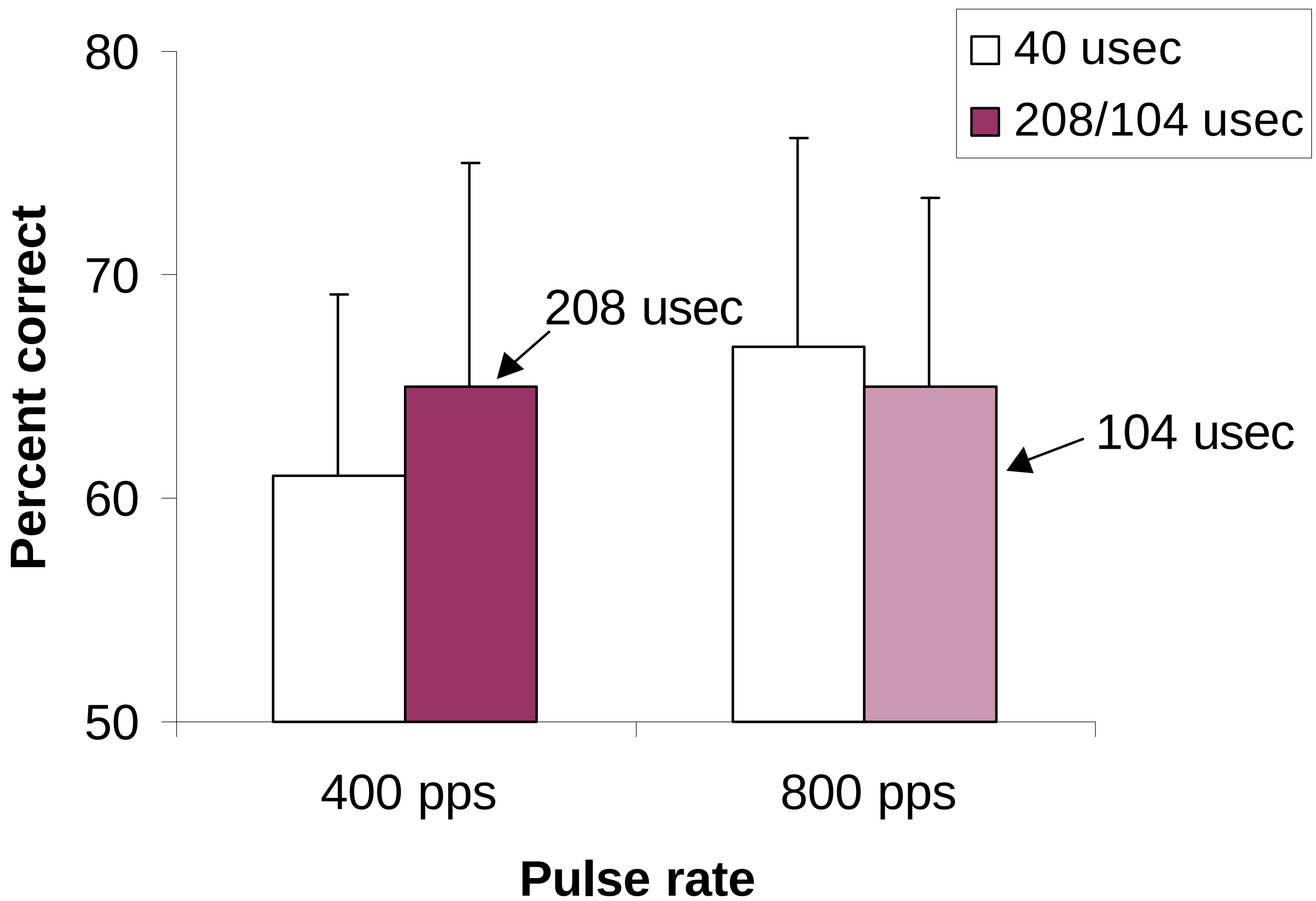
Discussion

- Significant improvements were obtained in stop identification (/iCi/), nasal identification (/uCu/), fricative and affricate identification.
- The large improvements in stop identification can be attributed to a better representation of burst cues achieved with higher rates.
- In front vowel (e.g., /i/) contexts, the release burst dominates the perception of place of articulation (Fischer-Jorgensen, 1972; Dorman *et al.*, 1977).

Pulse width

- Low-rate CIS processors can also be implemented by increasing the pulse width.
- Larger pulse width is often associated with lower thresholds, hence larger dynamic range.
- For the same fixed rate of stimulation, what is the effect of pulse width on consonant recognition?
- Pulse widths of 40, 104 and 208 μsec/phase were compared using 400 and 800 pps CIS processors.

Effect of pulse width for a fixed rate



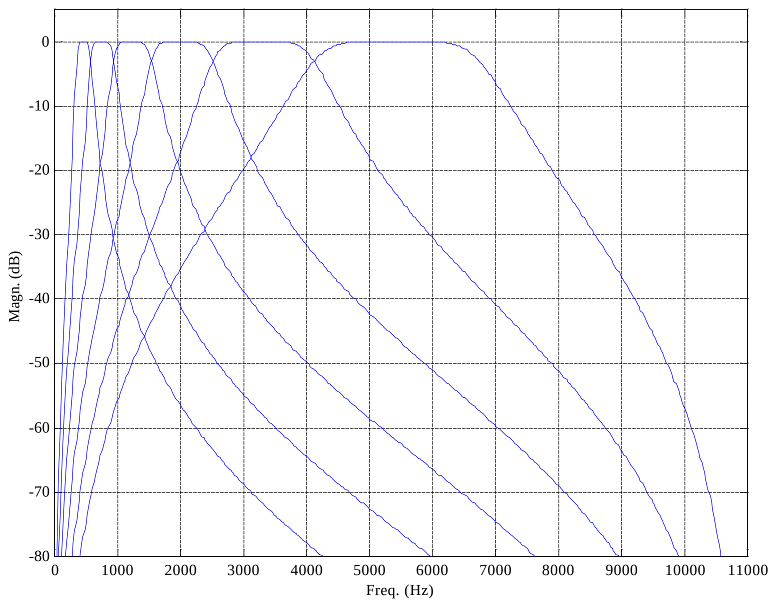
Signal Bandwidth

- In most commercial devices, the spectrum is bandlimited to 0-6 kHz.
- The question we ask in this experiment is: "Is there more information beyond 6 kHz which could be beneficial, particularly for the perception of consonants which contain high-frequency information? "
- To answer that question, we examined recognition of consonants bandlimited to 6.4, 8.4 and 9.9 kHz.

UTD

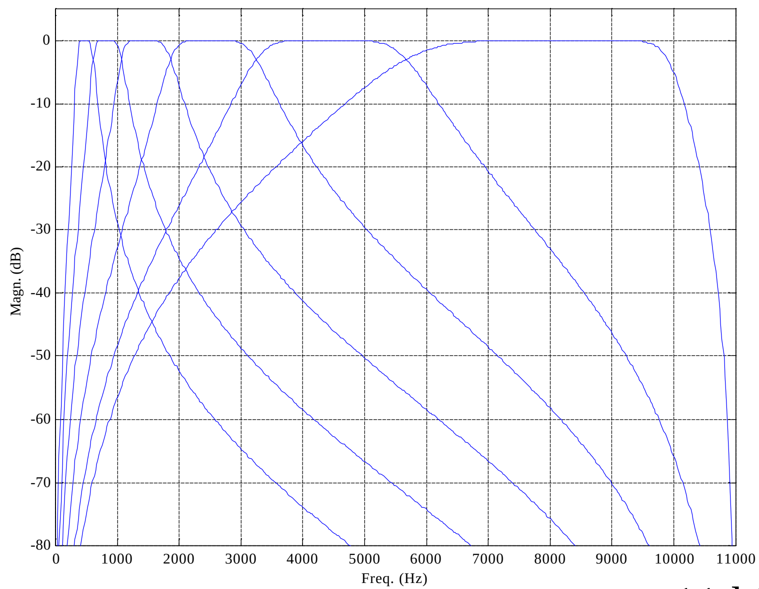
Frequency band allocations for 6.4 and 9.9 kHz bandwidths

6.4 kHz



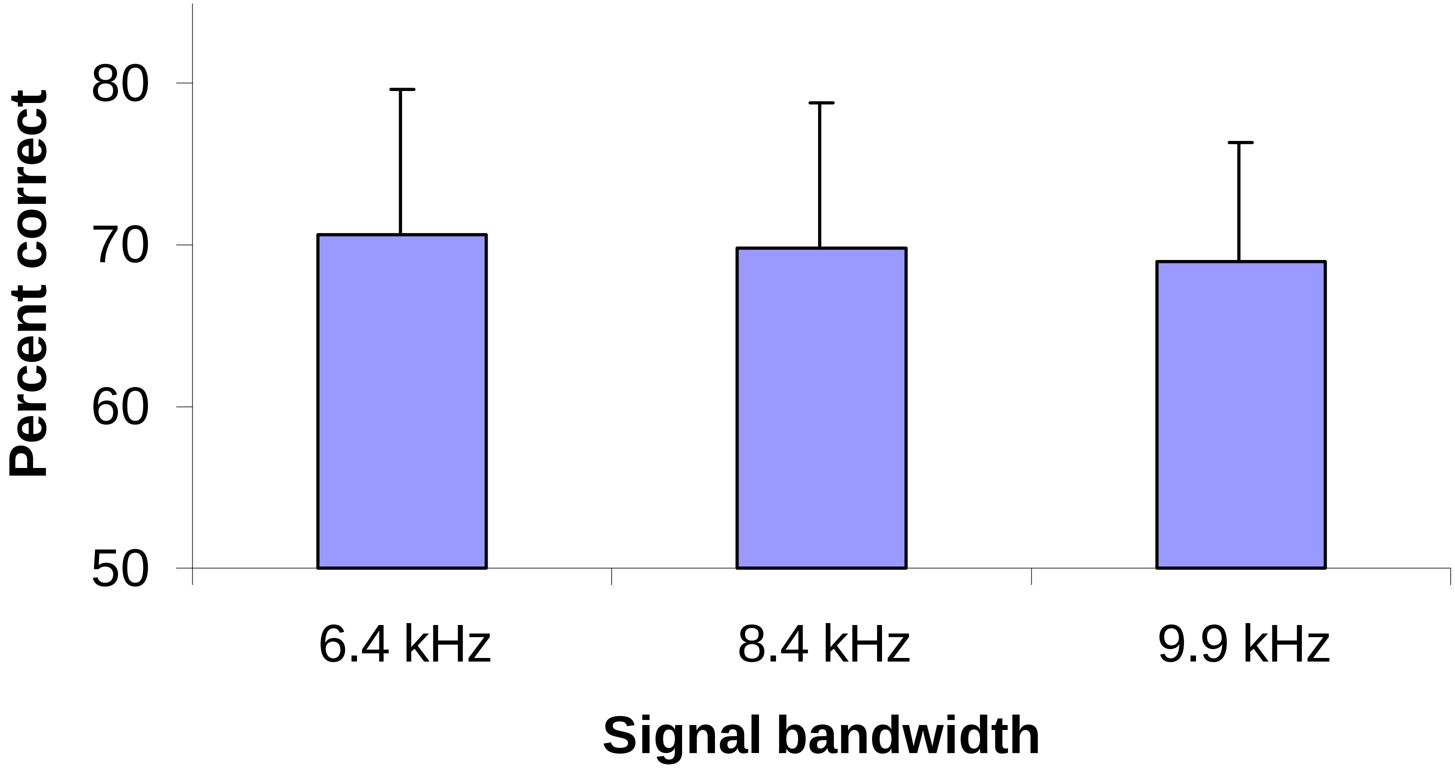
11 kHz

9.9 kHz



11 kHz

Effect of signal bandwidth

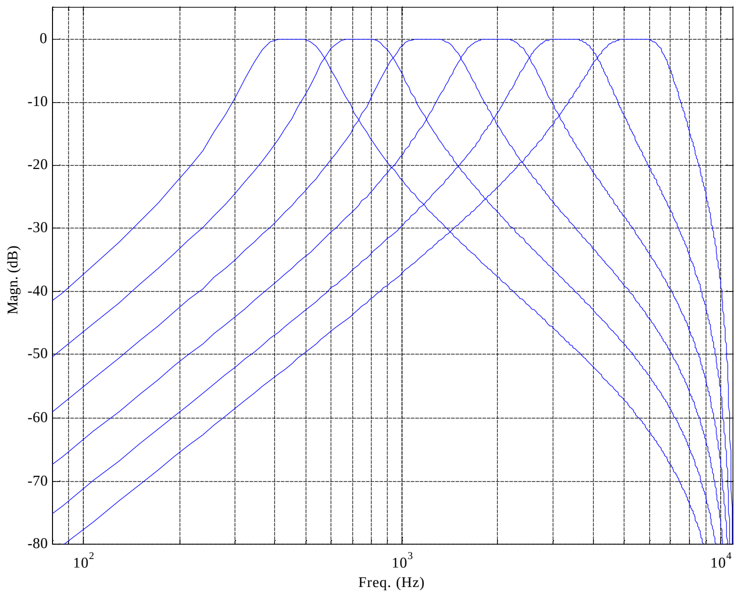


Bandpass-filter order

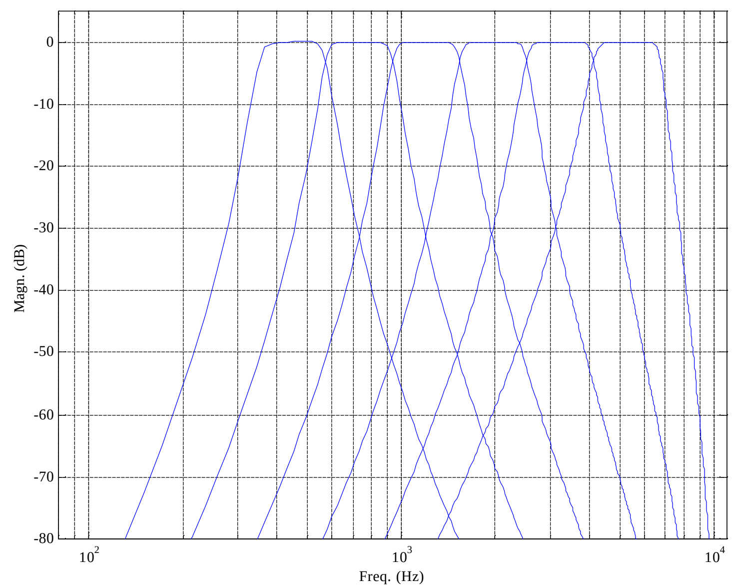
- The order of the bandpass filter affects the roll-off of the filter's frequency response.
- High order filters typically have steep rolloffs, and low order filters have shallow rolloffs.
- Steep filters ought to produce a better (perhaps more faithful) representation of the spectrum.
- Is that important, however, for consonant recognition?
- To answer that question, we examined consonant recognition using 4, 6, 8 and 10^{th}-order filters.

Frequency responses of 4th- and 10th-order Butterworth filters

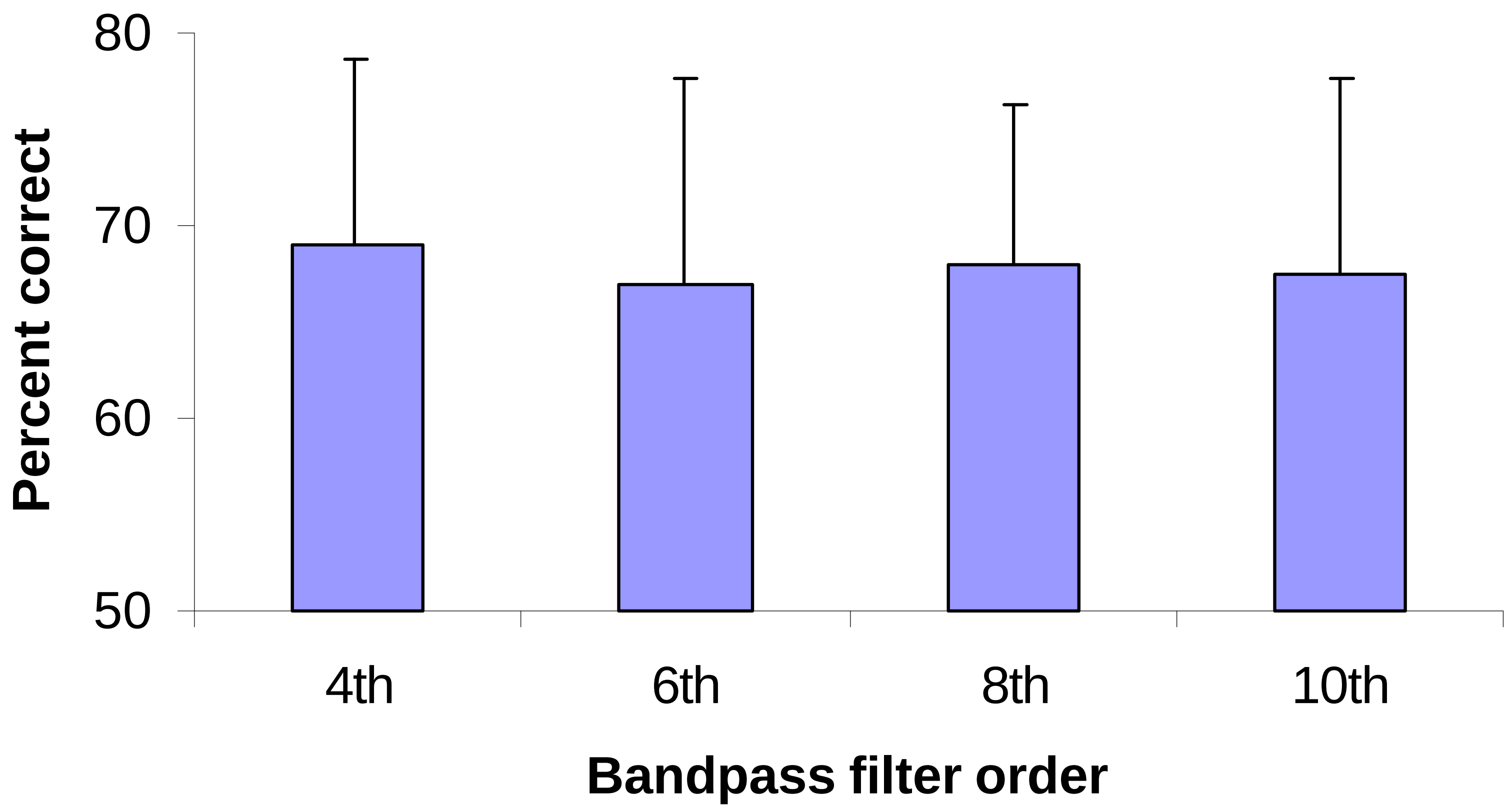
4th order



10th order



Effect of bandpass-filter rolloff



Discussion

- The filter rolloff does not seem to be have any effect in performance, at least in consonant recognition.
- Most likely, the filter rolloff may be more important in vowel recognition.

Shape of compression function

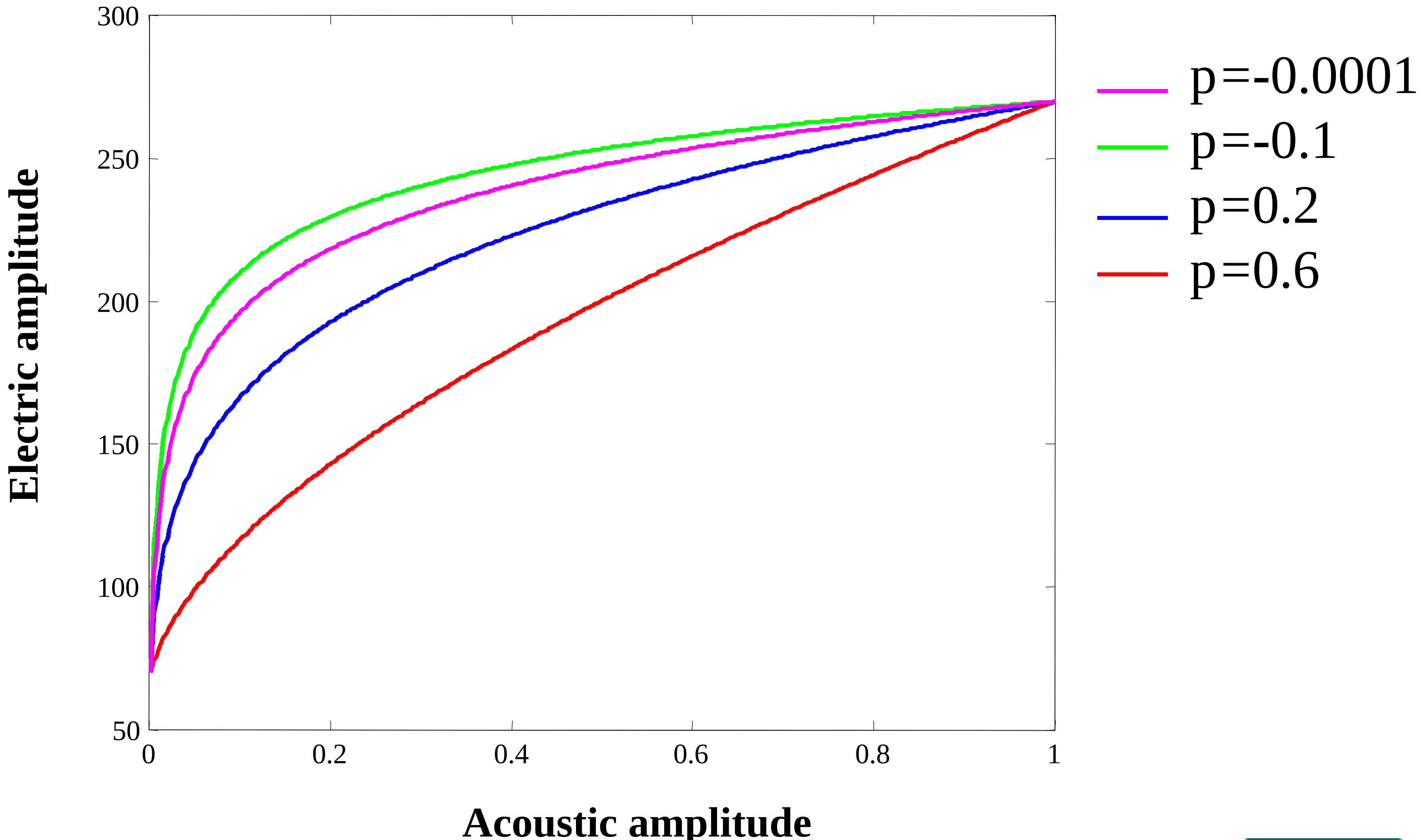
- Acoustic amplitudes were mapped to electric amplitudes using:

$$Y = a\,X^{p} + b$$

where Y is the electrical amplitude, and X is the acoustic amplitude. “a” and “b” are constants chosen to obtain THR and MCL.

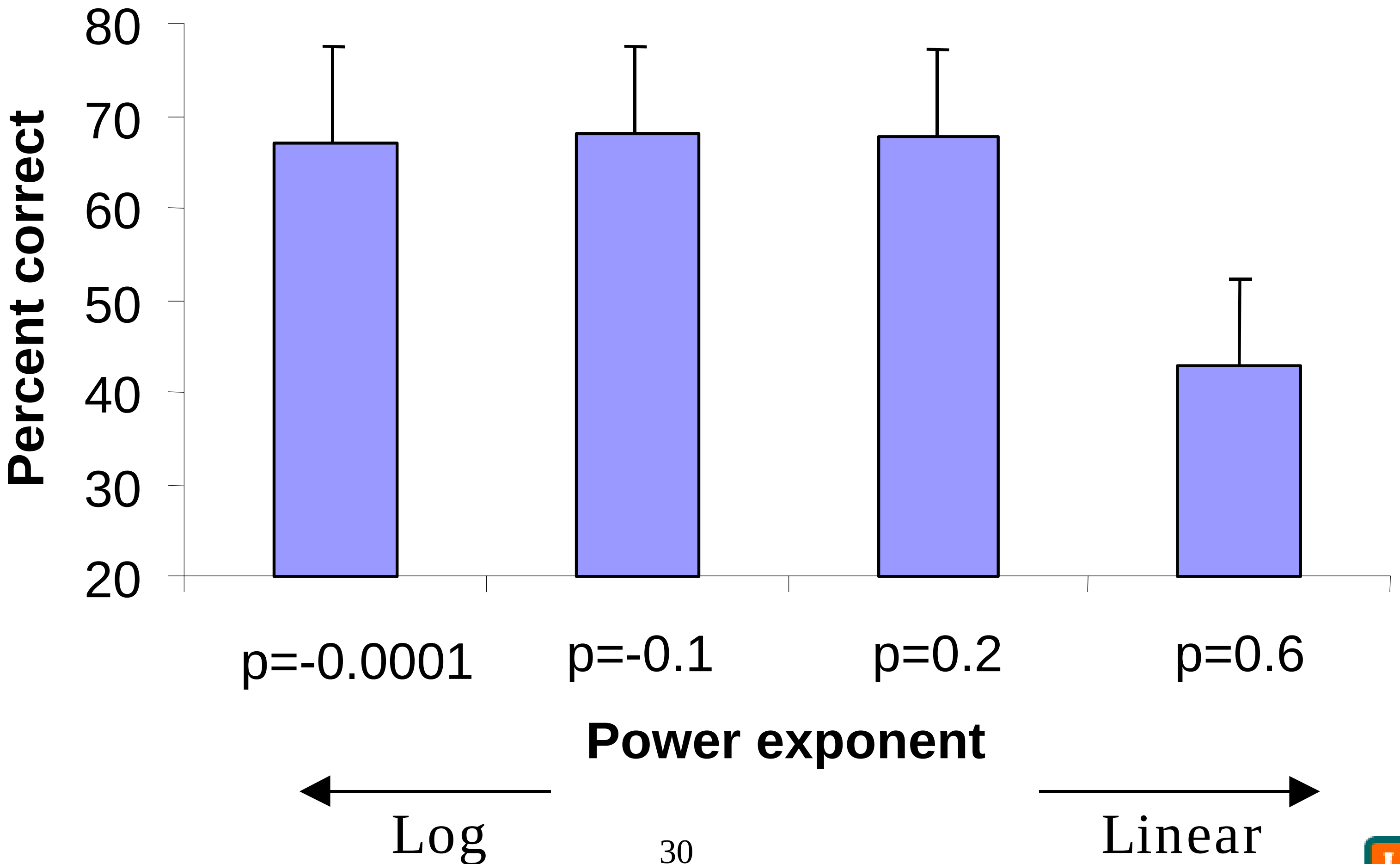
- The shape of the compression function was varied by modifying the power exponent *p*.

Compression Functions



UTD

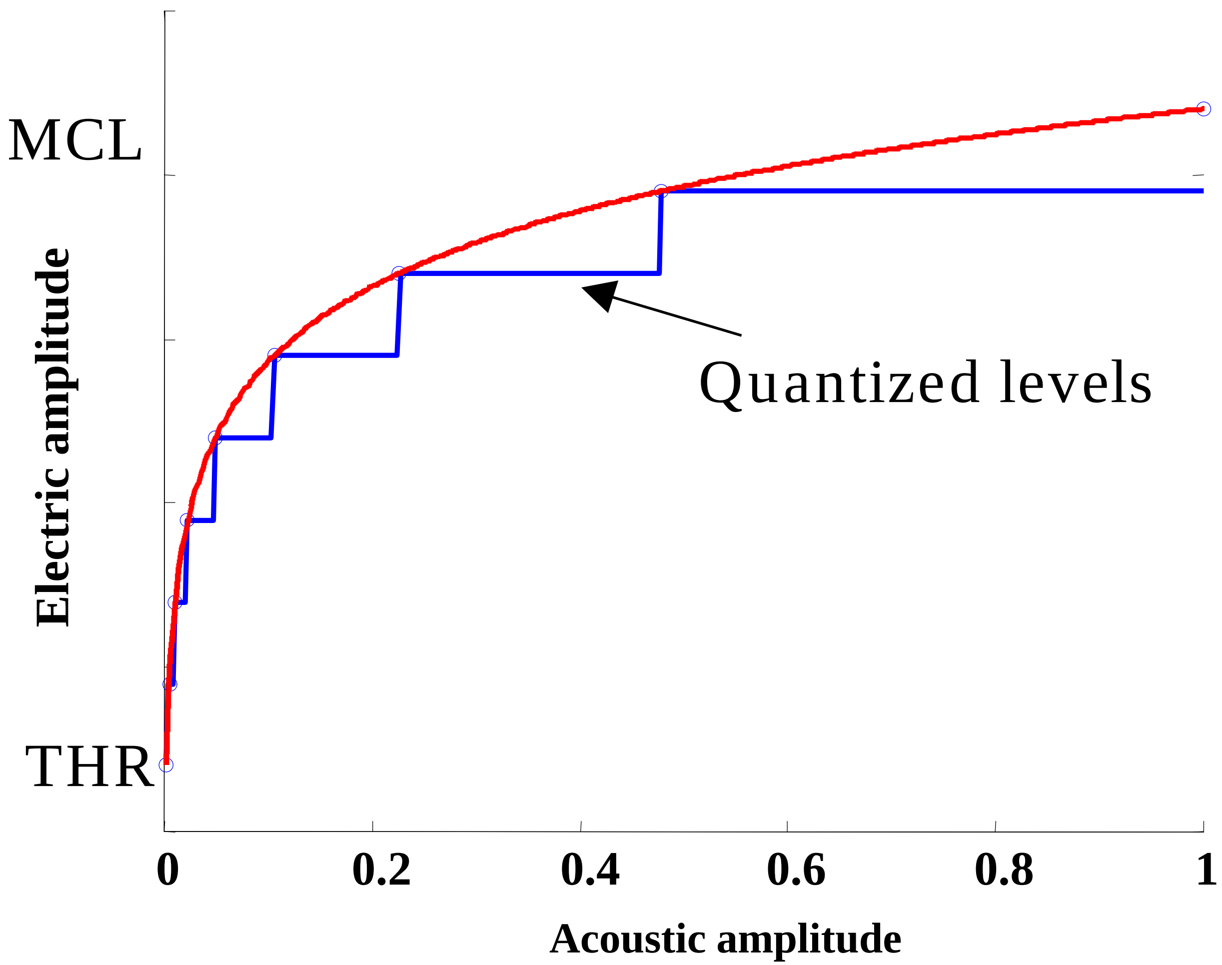
Effect of compression function shape



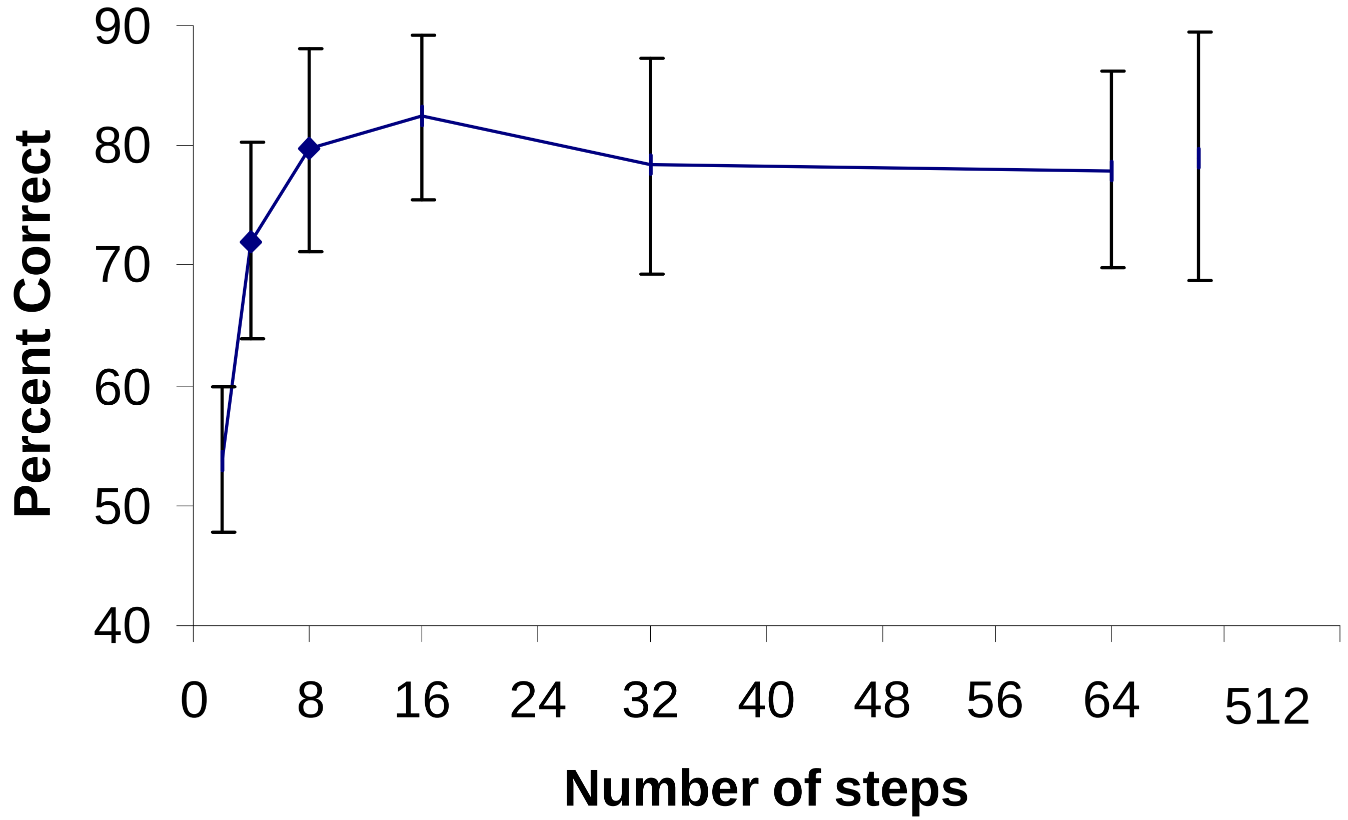
Compression function resolution (number of steps)

- This experiment addresses the question: What is the minimum number of discriminable steps needed to maintain high levels of consonant recognition?
- Is the answer to the above question different for poorly-performing and better-performing patients?
- To address the above questions we quantized the electrical dynamic range into Q number of steps (Q=2, 4, 8, 16, 32, 64).

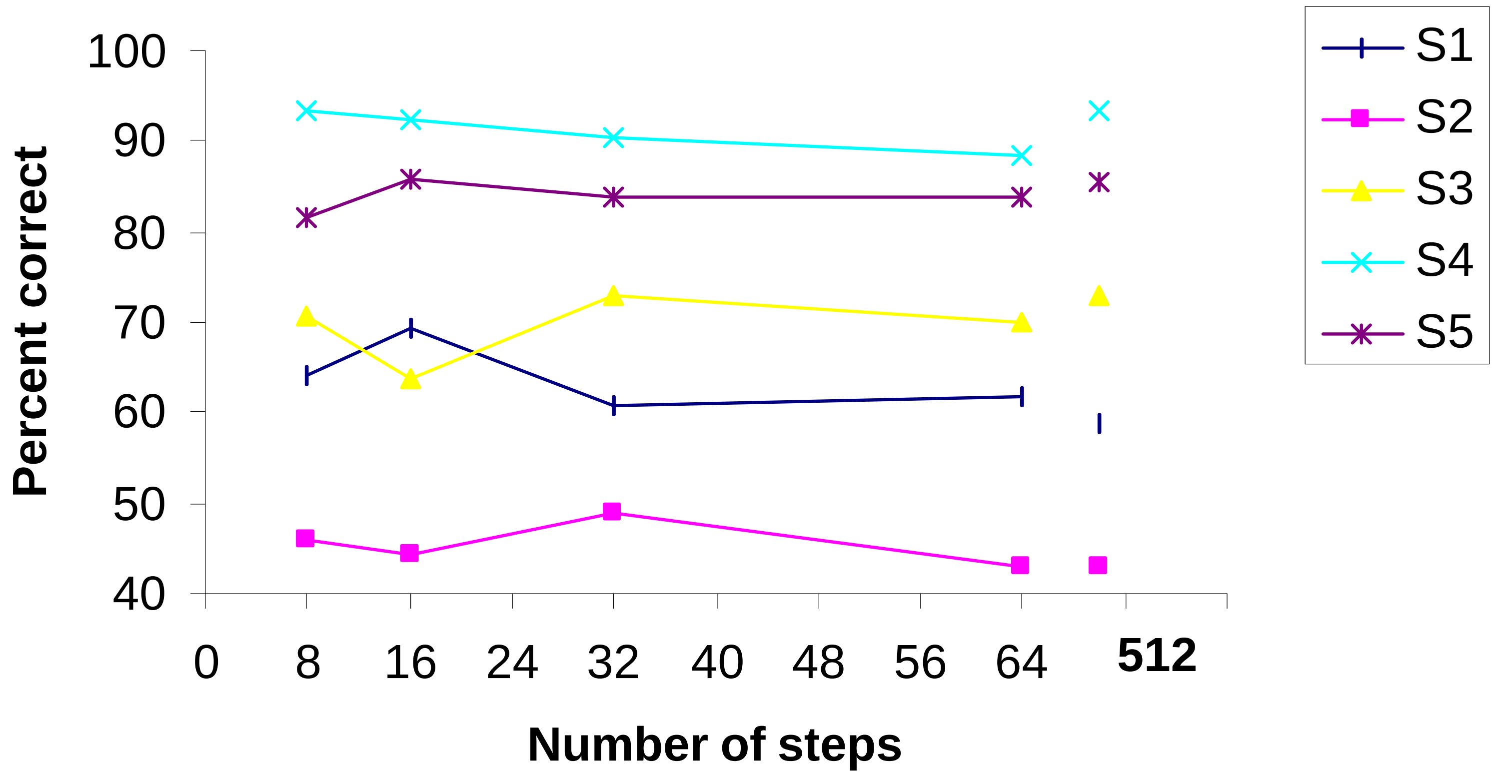
Compression function quantized into 8 steps



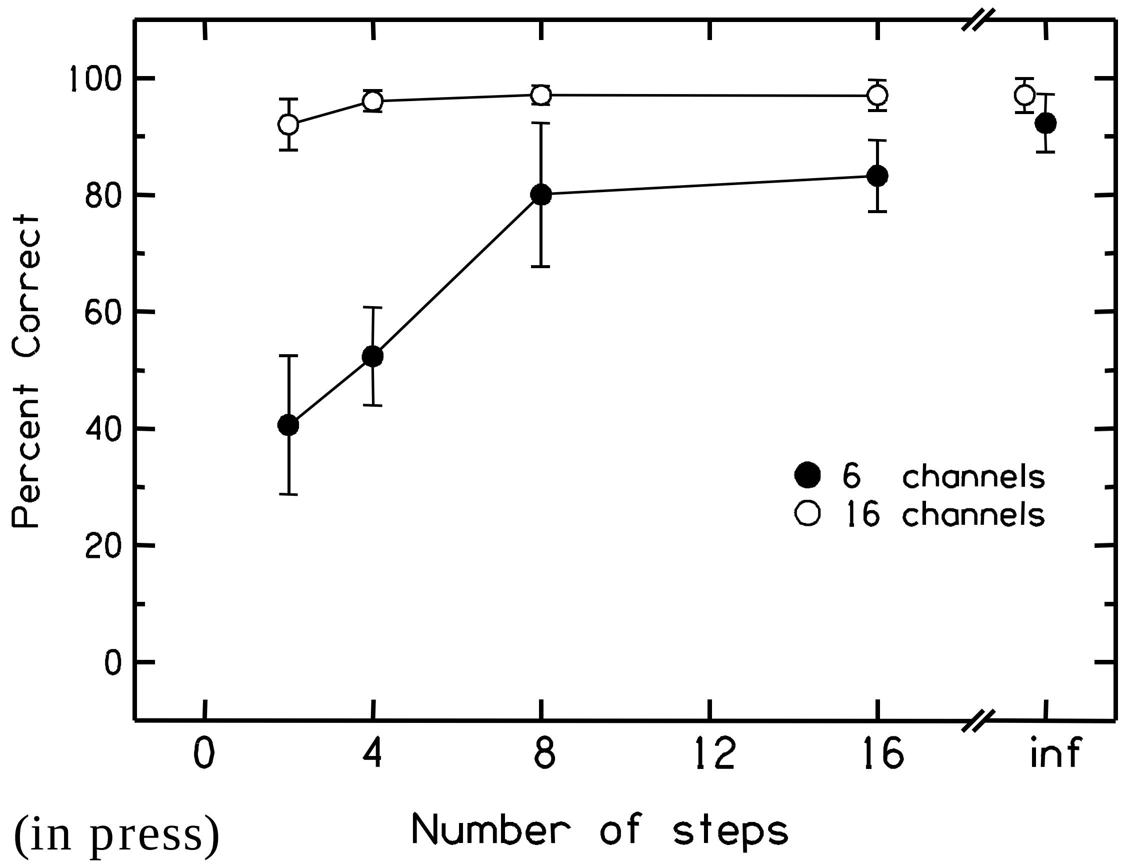
Effect of number of steps on consonant recognition (n=3)



Individual subject's performance (n=5)



Results from acoustic simulations using normal-hearing listeners



Loizou *et al.* (in press)
J. Acoust. Soc. Am.

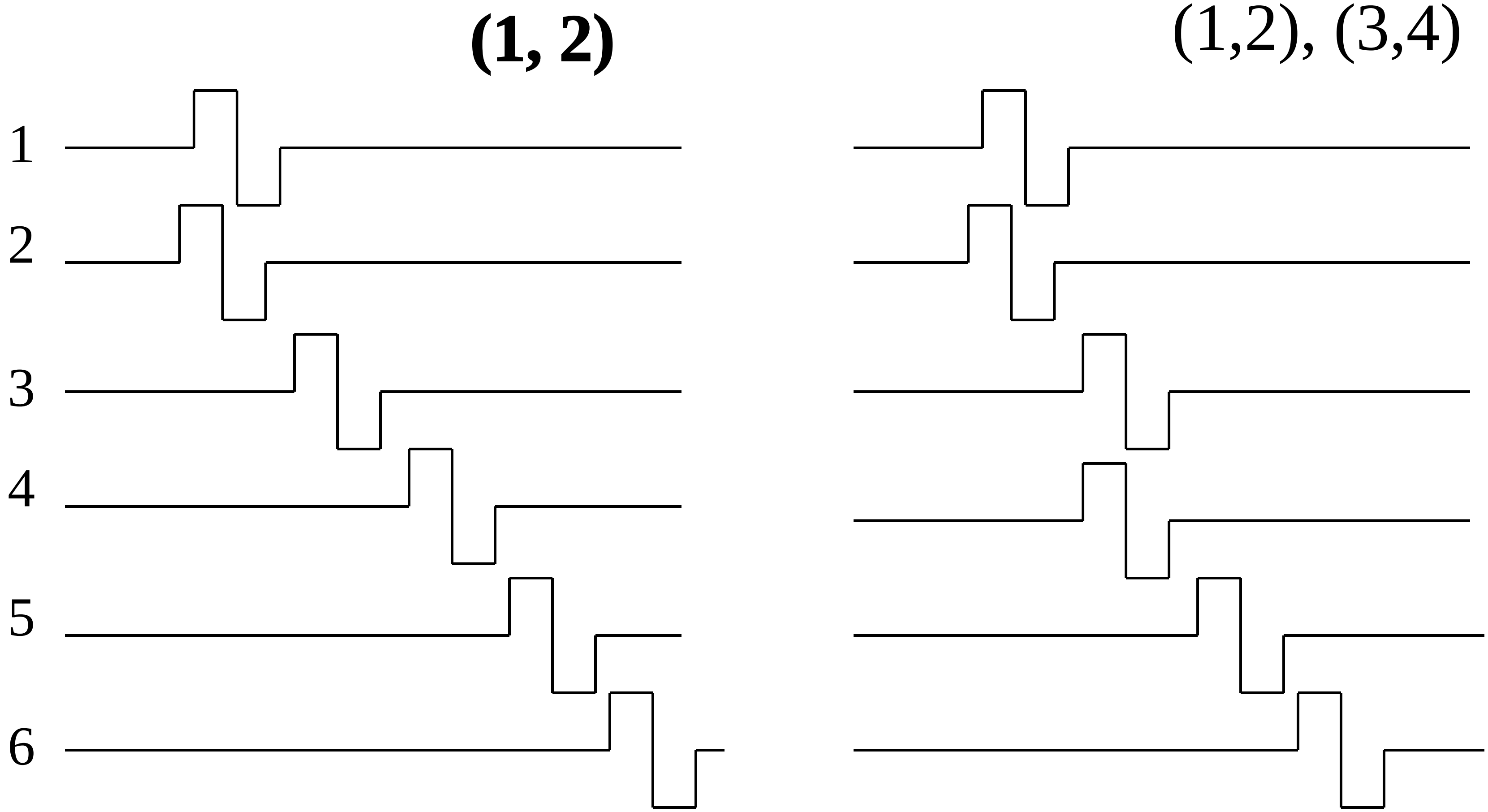
Discussion

- Only a small number (8) of steps is needed for consonant recognition.
- Performance for both poorly-performing and better-performing patients asymptotes at 8 steps.
- This suggests that the performance of poorly-performing patients is not limited by the small number of steps.

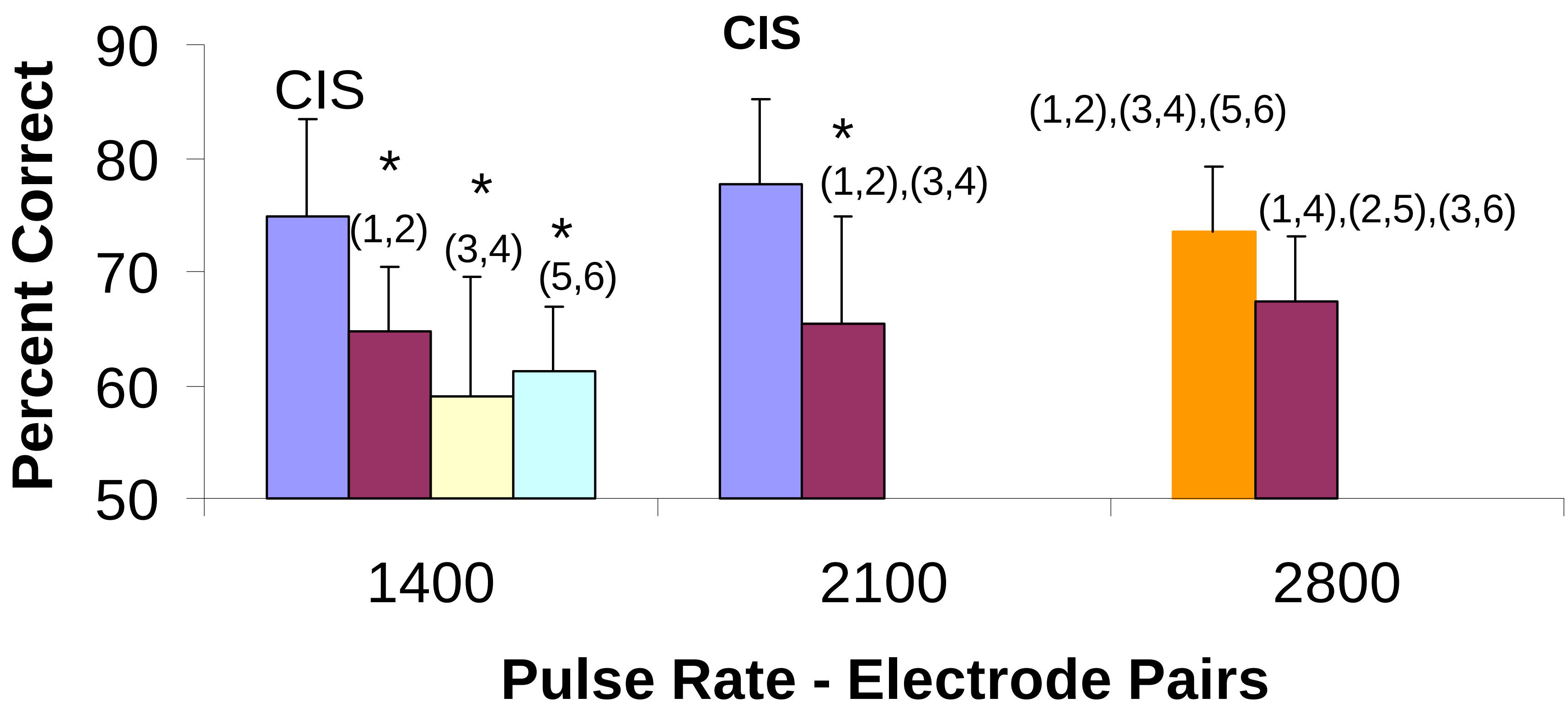
Paired-Pulsatile Processors (PPS)

- Within one cycle, PPS stimulates a pair of electrodes simultaneously.
- In this experiment, we chose to stimulate adjacent electrodes to create channel interaction.
- We wanted to systematically evaluate the effect of channel interaction, and identify which electrode-pair interaction has the most detrimental effect in consonant recognition.

Examples of pairs of electrodes studied with PPS



Effect of channel interaction (n=4)



1 - most apical
6 - most basal

* $p < 0.05$

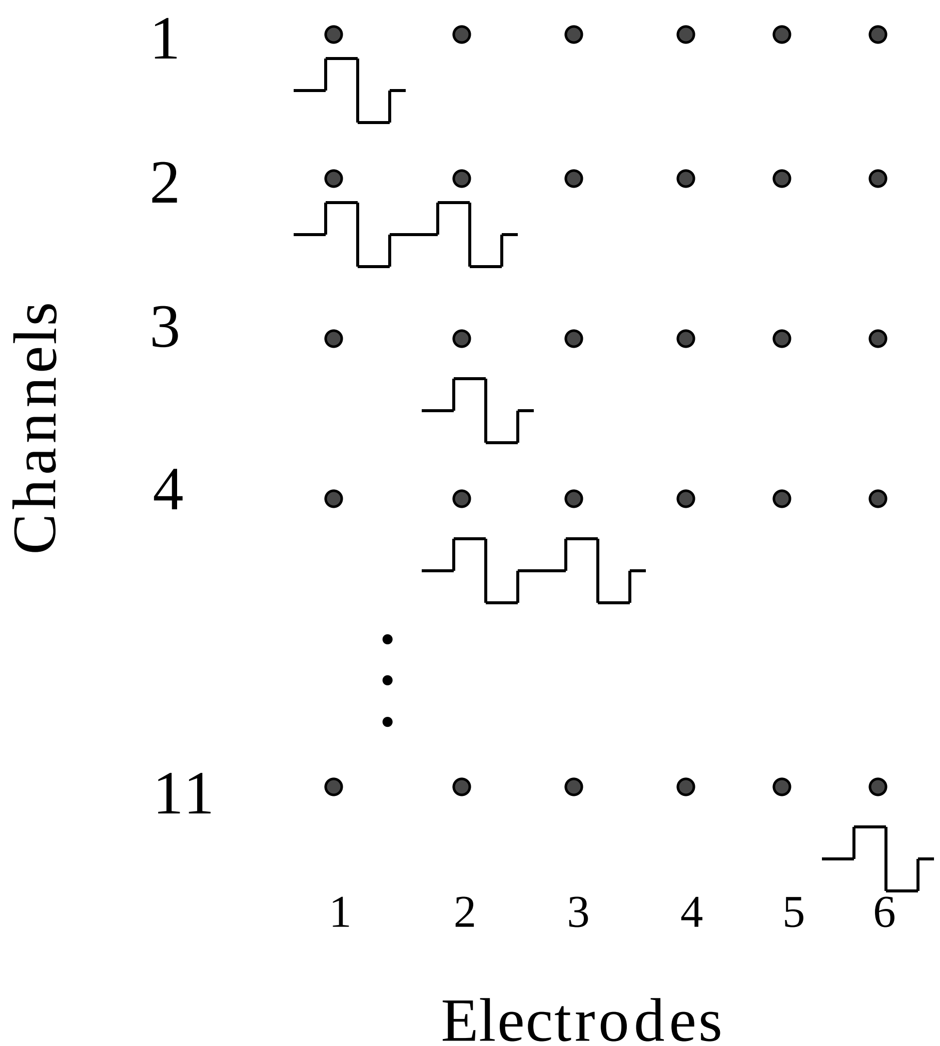
Discussion

- Even a small, localized channel interaction produced a decrement in consonant recognition.
- The most detrimental effect on consonant recognition was produced by electrode pair (3,4).
- That is probably because, channel interaction at electrodes 3 and 4 distorts / destroys information about F2.

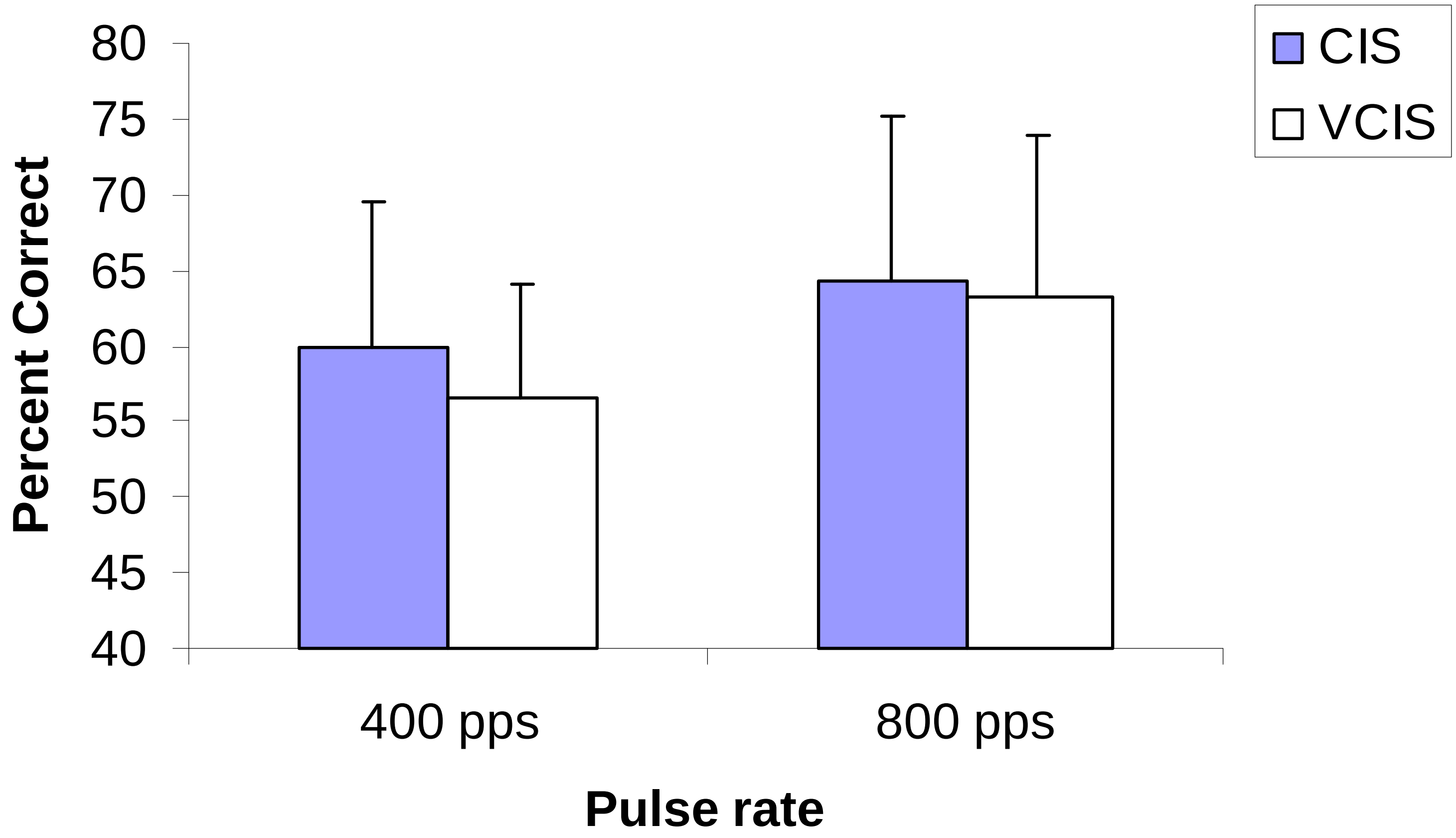
Virtual-channel CIS processors (VCIS)

- VCIS processors (Wilson et al., 1992) provide pitch percepts that are different from those elicited by stimulation of single electrodes.
- Pitch percepts can be controlled by simultaneous stimulation of adjacent electrodes and by manipulating the ratio of the corresponding pulses (Wilson et al., 1993).
- VCIS offer the possibility of increasing the number of channels beyond the number of available electrodes.

11-channel VCIS processor



Results



80
75
70
65
60
55
50
45
40
Percent Correct
CIS
VCIS
400 pps
800 pps
Pulse rate

Discussion

- VCIS processors did not yield any improvements in consonant recognition, at least for the pulse rates studied.
- Some patients, however, reported improvement in speech quality. Speech sounded more natural and more clear. Some patients enjoyed listening to music with VCIS.
- The full potential of VCIS processors has not been exploited. Further studies are needed.

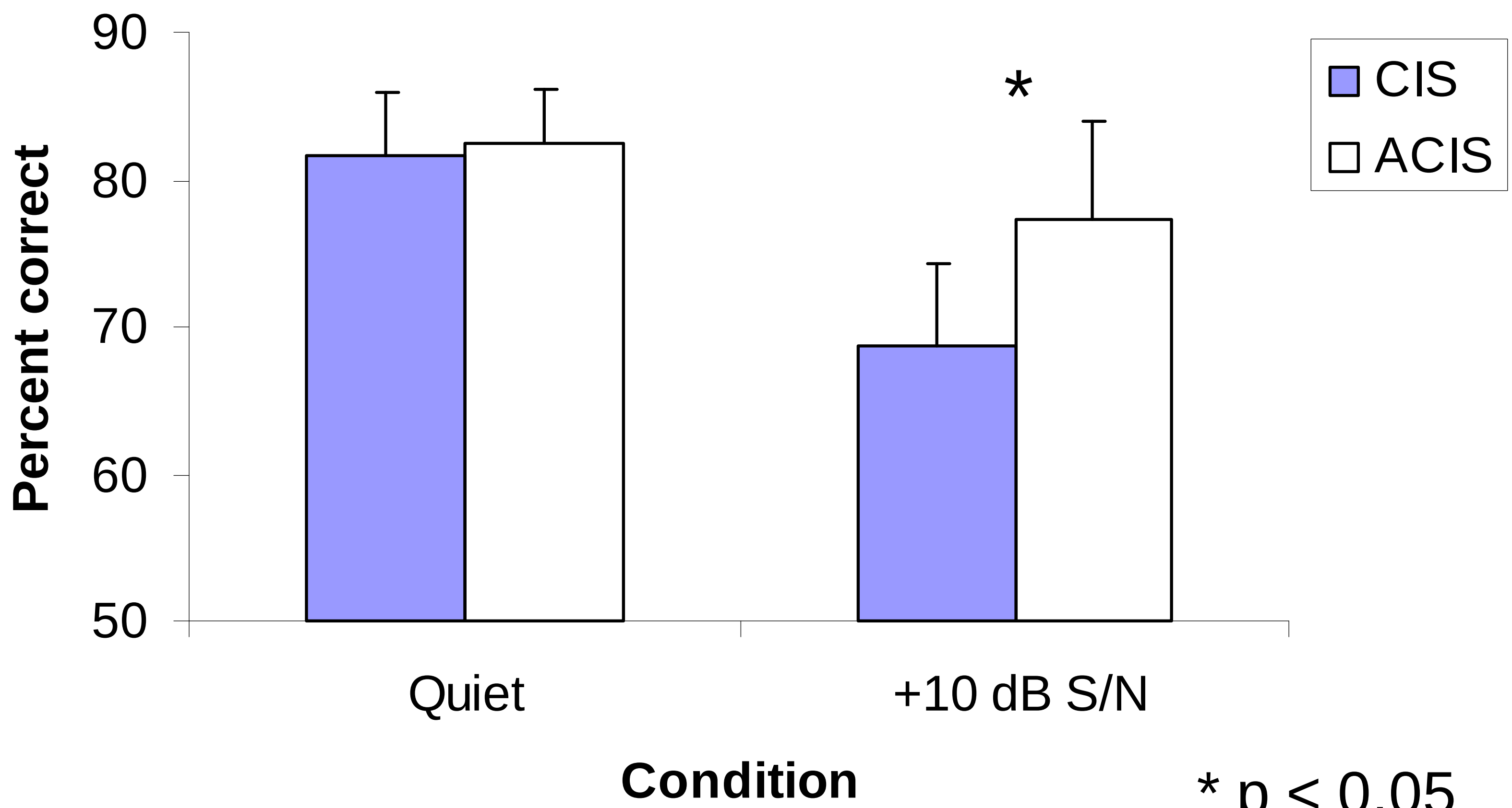
Moving-Average CIS processor

- The CIS strategy samples the speech envelope (obtained after rectification and low-pass filtering) at the same rate as the stimulation rate.
- Envelope outputs are “grabbed” every T seconds and used for stimulation. All envelope outputs obtained within T seconds are discarded.
- This envelope-sampling scheme will most likely miss important information (e.g., short stop-consonant transitions) at low rates.

Moving-Average CIS (ACIS)

- A different scheme (ACIS) was implemented to avoid missing perceptually important envelope information.
- Rather than sampling the envelope every T seconds, a moving window (of duration V < T seconds) is employed to obtain the current envelope output.
- The envelope amplitude used for stimulation is obtained by computing the RMS energy of all the amplitudes within the V-sec window.

Comparison of CIS vs. ACIS on /aCa/ recognition at 400 pulses/sec (n=5)



* $p < 0.05$

V=1.5 msecs

Conclusions

- Of all the parametric variations of the CIS strategy, the pulse rate had the most positive effect on speech recognition.
- Higher rate (2100 pps) CIS processors yielded a significantly higher performance on open-set recognition than the lower rate (<= 800 pps) CIS processors.
- Even a small, localized channel interaction yielded a decrease in consonant recognition.
- Only a handful (8) of steps is needed for consonant recognition by poorly-performing and better-performing patients.

Conclusions

- The full potential of VCIS processors has not been exploited. VCIS offers the possibility of increasing the effective number of channels.
- A multi-vowel consonant test (/vCv/) is recommended for assessing CI patient's performance.
- We have not reached the full potential of the CIS strategy. The performance of the CIS strategy can be further improved either by using alternative CIS implementations (e.g., ACIS in the present study) or by post-processing the envelope amplitudes.