Mixed Stimulation Rates for Encoding Temporal Cues in Bilateral Cochlear Implants

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INTRODUCTION

Bilateral cochlear implants (CI) provide benefits to recipients, but there is a significant gap in performance on spatial hearing tasks relative to performance of normal-hearing (NH) listeners. Much of the ability of NH listeners to localize sounds in the horizontal plane depends upon being able to extract and utilize the interaural time differences (ITDs) in the "temporal fine structure" (TFS) of sound between the two ears at frequencies below 1.5 kHz (Wightman and Kobayashi 1995; Wightman and Middlebrooks 2002). Most contemporary CIs stimulate the auditory nerve with constant-rate, high-rate electric pulse trains and not the TFS (Wilson et al. 1991; Amdt et al. 1999). These strategies may allow for adequate envelope ITD representation, but the loss of TFS may account for many of the deficits in bilateral hearing aids compared to NH. Though CI listeners can use the time cues in low-rate pulse trains for ITD discrimination and monaural localization, better speech recognition is generally achieved with high-rate stimulation (Luizou et al. 2000; Galvin and Fu 2005). The present study explored this tradeoff to better understand how high rates and pulse timing utilizations for ITDs with low rates.

METHODS

Three tasks were used to systematically examine the effects of channel pulse rate and pulse timing on ITD discrimination. ITD lateralization, and speech recognition in quiet by CI listeners. Stimuli consisted of speech tokens processed at low, high, and mixed electrical stimulation rate presentations, synchronized on 8 binurally pitched-electrode pairs. For each rate combination, two test rates were tested: a novel strategy which preserves a representation of acoustic TFS information in the pulse timing and the Continuous Interleaved Sampling (CIS) strategy, which does not.

Speech recognition in quiet (100 words per condition)

• 4 or 5-word sentences (from Kidd et al. 2008 corpus) were translated from the 500 words per condition (ITD = 0 ms).

• Test stimuli were presented to the CI users.

• Listeners' task was to indicate the perceived source of a sound presented along a 160° arc probed at 5°.

Lateralization vs Speech Recognition

• Rate combinations:

  1. low rates (200-173 Hz) on all electrodes
  2. mixed rates; low rates on four apical electrode pairs, high rates on four basal electrode pairs
  3. high rates (984-1547 Hz) on all electrodes

Processing Strategies

CIS: constant interstimulus interval; pulse train carrier rates are equal to average rates of corresponding stimulus tokens in the TFS strategy.

TFS: pulse train carrier consists of pulses timed to the positive-going zero crossings of low-kHz waves, where k denotes the imaginary part, k = k+ denotes the Hilbert transform, and p is the band-pass filtered acoustic envelope appropriate for low-rate (100-173 Hz) and high-rate (984-1547 Hz) temporal fine structure extraction.

Envelopes for both strategies were extracted via a short-time Fourier transform method using 120-point windows, 256-point overlap, and 220-point overlap to compress the listeners' dynamic ranges using a psychophysical function with exponent = 1.3. Frequency bars were allocated into 8 channels with corner frequencies logarithmically spaced between 195 and 16015 Hz.

RESULTS

Table 1: Eight bilateral CI listeners participated in each of these experiments. All subjects were cochlear device recipients and used the ACE processing strategy.

Table 2: The listeners' overall average lateralization responses for speech tokens containing only ITD location cues. Dashed lines indicate average listeners, and solid lines indicate linear best fit for, which statistics are included in the lower-right corner of each chart.

Table 3: Significant levels of strategy, rate, and strategy-rate interaction effects due to ANOVA in discrimination JNDS, lateralization slopes, and discrimination JNDS. "Within-subjects (repeated measures) ANOVA in discrimination JNDS, accounting for variability at each set of conditions, also revealed a significant effect of rate combination (p < 0.001)."