RATE DISCRIMINATION AT LOW PULSE RATES: COMPARISON BETWEEN NORMAL-HEARING AND COCHLEAR IMPLANT LISTENERS AND INFLUENCE OF INTRACOCHLEAR STIMULATION SITE

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INTRODUCTION

Being able to perceive changes in pitch is important for the separation of sound sources, and is therefore an important cue for speech recognition in noise. Even if pitch discrimination is best when spectrally-resolved harmonics are presents, Normal Hearing (NH) subjects also discriminate pitch based on purely temporal cues. CI users do not have access to resolved harmonics but can discriminate pitch based on temporal cues, wich can be transmitted by the CI either by sending high-rate pulse trains amplitude-modulated at the F0, or by sending low-rate pulse trains at the F0.

Temporal pitch perception in CIs remains weaker than in NH, and is usually limited to rates below about 300 pulses per second (pps).The present study aims to better understand the limitations of the temporal pitch mechanism in CI users by focusing on rate discrimination at low pulse rates (ranging from 20 to about 100 pps).

This focus on low rates was motivated by data obtained in NH listeners showing that frequency difference limens (DLs) for bandpass filtered harmonic complexes were lower when the complex was filtered in a low than in a high frequency region (Krumbholz et al., 2000). Most importantly, this result was true even when the lowest harmonics present in the passband were clearly unresolved (rank > 12), suggesting that temporal cues are more salient when originating from the apex. However, given their stimuli all had a fixed bandwidth in Hz, it remained unclear whether the better performance observed in low frequency regions was due to the greater portion of neurons being excited or simply to the fact that it was lower.

How does pitch discrimination behave at fairly low rates ?
If we have to convey temporal pitch information in CI, what electrode to choose?

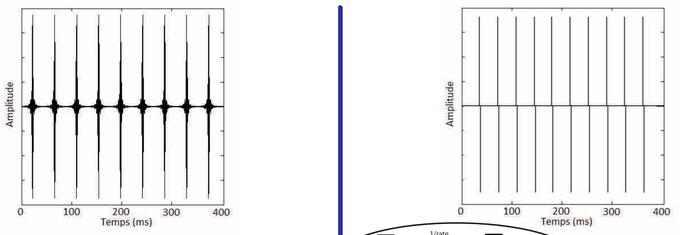
MATERIAL AND METHODS

Temporal pitch discrimination

In order to measure temporal pitch at the most apical and basal possible places of the cochlea, we tested Med'El CI users.

Simulations in NH subjects, comparison with CI users:

ACOUSTICAL STIMULI **VS** **ELECTRICAL STIMULI**



All acoustical stimuli must simulate the electrical pulse trains caused by the activation of a CI electrode (Carlyon, Long and Deeks, 2008).

Acoustical pusle trains : harmonic complex tones in sine phase.
Spectrally restricted to high frequency regions

Electrical biphasic pulse trains.
500ms duration monopolar configuration 45 µs/ phase anodic-first

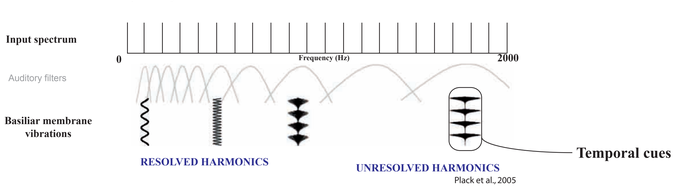
Psychophysical measures :

3I2AFC procedure (Levitt, 1971), a measure ends after 10 reversals

Threshold (%) = rate difference in % between the standard and the mean of the last 6 reversals

How to convey only temporal pitch cues to NH subjects ?

The cochlea operates as a set of band-pass filters having center frequencies ranging from low frequencies to high frequencies. It is also known that the bandwidth of the auditory filters increases with the center frequency.



The width of these filters increases with the frequency: the spectral analysis therefore degrades at high frequencies.

All stimuli spectrally restricted to high frequency regions : keep all harmonics unresolved

EXPERIMENT 1: SIMULATIONS WITH NH SUBJECTS

Acoustical stimuli for NH subjects:

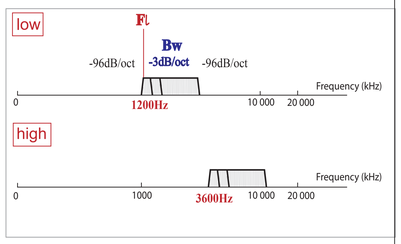
24 conditions: 4 **F0s** x 2 Frequencies regions (Fc) x 3 Band-Widths (Bw)

4 x F0s : 20,35,60,104 Hz.

2 x Fc : low 1200Hz, high 3600 Hz

3 x Bw : narrow, ΔF/F= 0.2 (low=250, high=750 Hz)
medium, ΔF/F= 0.6 (low=750, high=2250 Hz)
wide, ΔF/F= 1.8 (low=2250, high=6750 Hz)

Comparable in Bw



Continuous background pink noise→mask distortion products

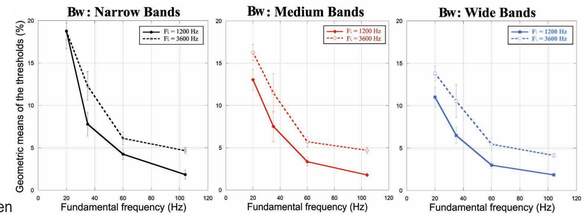
Narrow Bw stimuli set at 15 dB SL
Fixed SNR at each auditory filter output
Overall levels vary from 47 dB SPL to 55 dB SPL

Rate discrimination with NH subjects:

As a function of F0 and Fc: Simulates different electrodes

6 normal hearing subjects were asked to complete the experiment of rate discrimination.

Error bars = +/- std error



Effects:
F0 (p<0.01)
Fc (p<0.01)
Interactions:
F0 * Fc (p<0.01)

Implications:
Discriminations thresholds get lower when F0 or Fc increase.
The threshold difference (between FI= 1200 and 3600 Hz) gets slightly better when the F0 increase.

NH performances improves when we stimulate a more apical region

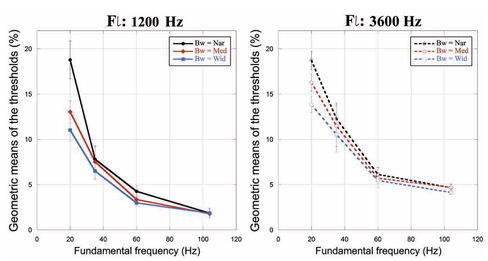
As a function of Bw: Simulates single- vs muti-electrodes or narrow electrode configuration (e.g. tripolar) vs. broad (monopolar)

The same results are ploted separated for each Fc, apical (1200 Hz) and basal (3600 Hz).

Effects:
Bw (p<0.01)
Interactions:
F0 * Bw (p<0.01)

Implications:
When Bw increases, performance improves, but this improvement is smaller at higher rates.

The small effect of Bw on F0 discrimination may explain why no effect of multi electrode stimulation has been observed on CI's pitch discrimination (Bahmer and Baumann, 2012).



NH performances slightly improves when the stimulus excites a larger portion of the cochlea

EXPERIMENT 2: PITCH DISCRIMINATION IN CI USERS

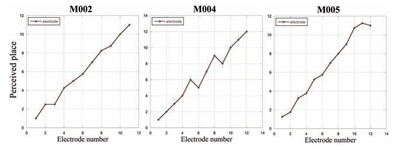
Preliminary experiments for CIU:

Based on the simulations, we expect CI users to be better when we stimulate the apex of the cochlea

Full results of 3 Med'El CI users are presented. Before measuring the rate discrimination, preliminary tests were performed:
- to verify that the electrodes elicited pitch sensations consistent with expected tonotopy (no electrode invertions).
- to measure / equalize the Most Comfortable Level (MCL) of each stimulus.

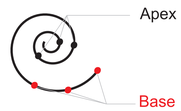
Electrode ranking:

How to choose the 2 electrodes ?
Midpoint comparison procedure (Long et al., 2005) on all active electrodes: which sound has the higher pitch ?



Electrodes of interest :

- 1 **most apical**, 1 **most basal** possible
- Similar thresholds and dynamic ranges
- No pitch inversion.

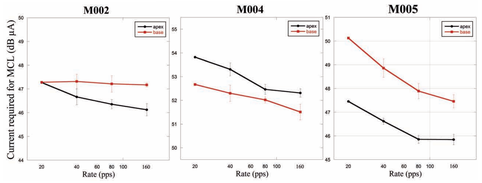


Most comfortable levels (MCLs):

Stimuli of different rates elicit different loudness sensations. In order to equalize the levels of all stimuli for the discrimination threshold task, MCLs at different rates were measured on the 2 electrodes and for the different rates: 20, 40, 80, 160 pulses per second (pps).

3 steps: - Measure of the MCLs
- Loudness adjustement of pairs of tones : 20vs40, 40vs80, 80vs160 pps

The level of each stimulus was obtained by interpolatation between these values, as a function of its rates.



Rate discrimination as determined by CI users:

8 conditions: 4 rates x 2 electrodes

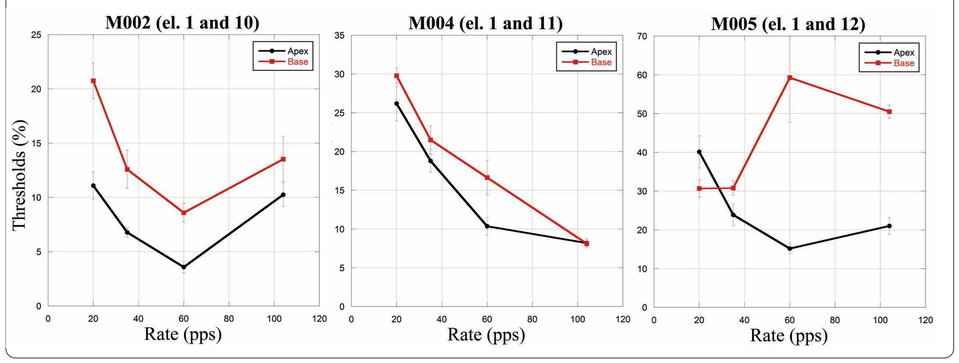
4 Different rates:
Rates = 20,35,60,104 Hz.

2 Different electrodes:
Electrodes = **apical**, **basal**

Results (preliminary):

Rate discrimination thresholds are overall lower when we stimulate the apex of the cochlea
(exeption of M005 at 20 pps)
Overall performances also improves when the rate increases
(exceptions: M002 at 104pps, M005 when stimulating the basal electrode).

Explanation ? For high-rate stimuli, neurons may not have the time to completely recover from refractoriness between the presentation of two pulses → therefore unable to fully respond to each pulse in the train.



Discussion:

Performance of NH: - improves when F0 increases
- improves when stimulating a more apical region

Confirm and extend the results obtained by Krumbholtz et al.
Who used same Bw in Hz at different Fc

- also slightly improves when we stimulate a larger portion of the cochlea (larger Band-widths), effect of loudness?

Performance of CI users: not finished yet, but preliminary studies on 3 subjects suggest that
- there is some variability between subjects.
- overall performances are worse than for NH.
- seem to be better when we stimulate the apex.

References:

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