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THE RELATIVE IMPORTANCE OF RATE AND PLACE: EXPERIMENTS USING PITCH SCALING TECHNIQUES WITH COCHLEAR IMPLANTEES

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Abstract. Pitch scaling was used to determine the dependence of perceived pitch on rate and place of stimulation using cochlear implants in post-lingually deafened adult subjects. For stimulation rates below about 500 pulses per second (pps), perceived pitch is a strong function of both rate and place. In this range, perceived pitch increases logarithmically with stimulation rate, but decreases with distance from the round window. A 2 mm displacement into the cochlea has an effect similar to that of halving the stimulation rate. Place resolution in this context is comparable with the inter-electrode spacing (0.75 mm). At rates approaching 1000 pps, rate has little effect on perceived pitch. An average of bipolar quality judgements showed that periodic pulsatile stimulation is least pleasant when low frequencies are applied to the region closest to the window.

Key words: multichannel cochlear implant, pitch perception, pitch scaling, rate pitch, place pitch.

Cochlear implants (CIs) work well for speech comprehension but poorly for music perception and recognition [1,2]. A project to improve music perception by CI users inspired this study into the way in which musical pitch depends on rate and place of stimulation. However, this question has broader scientific implications because of the long standing debate over the way in which pitch is coded in the normal ear. This debate continues because rate and place of stimulation are strongly correlated in the normal ear. With a CI, however, rate and place of stimulation can be controlled almost independently.

Most speech processing strategies perform poorly with music because they extract formants and other low resolution features of the spectrum or spectral envelope. These strategies include multi peak and continuous interleaved stimulation and are described elsewhere [3]. Most of these strategies map different, relatively broad ranges of frequency to different electrodes and thus stimulate different regions of the cochlea. Several recent strategies stimulate at an arbitrary rate. This low resolution in the frequency domain and low information content in the time domain result in poor pitch perception and thus in poor perception of melody and harmony in music.

Studies using CIs to elicit pitch have concentrated on the rate [4] and place [5] of stimulation. Other techniques which affect pitch are the modulation of two rates [6], non-simultaneous aggregation of two rates [7], varying pulse width [8] and varying the amplitude of stimulation [9,10]. In the rare case where a subject has both an implant and some residual acoustic hearing in the unimplanted ear, it is possible to do pitch matching experiments. Dorman et al. [11] found that, for constant electrode stimulation frequency, the electrode number correlated strongly with the frequency of a matched acoustic stimulus, and that, at fixed electrode position, electrode stimulation frequency was strongly correlated with acoustic frequency.

This study uses the technique of pitch scaling [12,13] (described below) which has the advantages that it does not require musical training and that subjects are not asked to adjust stimuli to "match" percepts which may differ in more than one perceptual dimension [4].

Experiments. Six post-lingually deafened adults volunteered for this study which comprised three test sessions lasting 1-2 hours. Their ages ranged from 35 to 72 and all had been implanted with a CI22m Cochlear Ltd multichannel device for between 2 and 11 years. All use "BP+1" mode where the stimulated electrode pair are separated by one temporarily inactive electrode. This mode was used in these experiments.

The stimuli were 1000 ms pulse trains of biphasic rectangular pulses. Pulse durations were 100 μs with 25 μs interphase gap. Stimuli were presented via purpose written testing software on a computer and a SPrint™ processor. Subjects adjusted all stimuli to equal loudness before testing began.

The pitch scaling technique described in [12,13] was followed. Subjects assigned a value on an arbitrary scale from 0 (very low pitch) to 100 (very high pitch). Presentation order was randomised and all stimuli were presented twice in a training block before data collection. Then, all stimuli were presented seven times in each data gathering block. The first pitch scale value for each stimulus was discarded to allow for an initial adjustment period [12]. Each subject's values were then converted to a percentage of the total scale range that they used during that series of experiments to allow comparison among subjects. The same protocol was used in two separate experiments conducted over different ranges of rate and electrode position.

Following each of the pitch scaling tests, each stimulus was presented twice and the subject was asked to assess the quality or timbre of the sound by indicating a position on a line between pairs of bipolar quality words: 'like–dislike', 'mechanical–natural', 'pleasant–unpleasant', 'clear–fuzzy', 'musical-not musical', 'natural–unnatural', 'colourful–colourless' and 'brilliant–dull'. A mean of these positions was taken to give a quality rating of the sound for that subject.

Results and discussion. One series of measurements used rates of 100-500 pps delivered to three closely spaced electrode pairs furthest from the window (most apical). Over this range, perceived pitch varies logarithmically with stimulation rate (Figure 1a). This invites a comparison with normal hearing in which, for pure tones, pitch varies logarithmically with acoustic frequency. Perceived pitch depends on place in the expected sense, decreasing with increasing distance from the window end. (This result is in qualitative agreement with the pitch matching experiments of Dorman et al [11].) In Figure 1a, the three electrode pairs are at separations of one electrode spacing or 0.75 mm. Thus a displacement of two electrode spacings has an effect slightly less than that of doubling the stimulation rate. The differences between electrode pairs 18-20 and 19-21 is significant at 0.05, which suggests that place resolution of one electrode spacing is possible in this context.

Figure 1b shows the results for a larger range of rate and place. Again, pitch decreases with increased distance of the electrode from the window. Pitch increases with stimulation rate over the range 100-500 pps but, above this rate, there is little further increase in pitch with rate, especially for the electrodes closest to the windows. This apparent saturation with stimulation rate may be related to the maximum firing rate of nerve fibres.

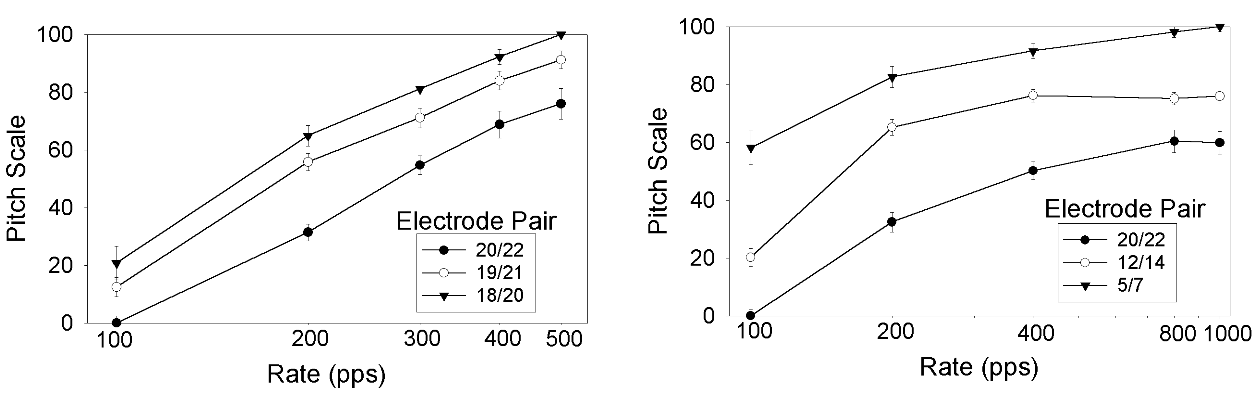

Figure 1. The average of the pitch scaled values for all subjects, ± standard error of the mean. The higher number electrodes are those that are inserted further (more apical) while the lower numbers (more basal) are closer to the window end of the cochlea.

Together, these results suggest that, for cochlear implant subjects using pulsatile stimulation, both rate and place contribute to pitch for low stimulation rates, but that place dominates at higher rates. The subjects in this study do not, of course, have normal hearing so the implications of these results for the rate-place debate in general are limited, but they are nonetheless suggestive.

The subjects' sound quality reports (Figure 2) suggest that periodic pulsatile stimulation is least pleasant when low rates are applied to the region closest to the windows: i.e. that region normally associated with high pitch. This is unsurprising: these post-lingually deafened subjects may have been comparing the implant stimulation with a remembered, or perhaps innate, rate-place correlation.

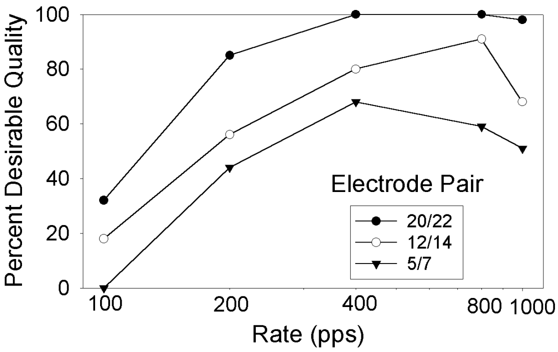

Figure 2. Subject quality ratings.

These results suggest that combinations of rate and place, especially at low frequencies, may be best suited to conveying pitch in processing strategies designed for music. The results also put a lower bound (~0.8 mm) on the capacity of the ear to resolve electrode position in the context of musical pitch, which suggests that a large number of closely spaced electrodes may have considerable advantages for pitch perception in the region above several hundred pps.

Conclusions. Perceived pitch is a strong function of both rate and place for stimulation rates below about 500 pps. In this region, perceived pitch increases logarithmically with stimulation rate. Perceived pitch also decreases with distance from the window, with a 2 mm displacement having an effect similar to that of halving of stimulation rate. At frequencies approaching 1000 pps, rate has little effect on pitch. An upper bound to the resolution of electrode position in the context of pitch judgement is comparable with inter-electrode spacing (0.75 mm) in the array used here.

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References

1. Schulz, E. and M. Kerber. Music perception with the MED-EL implants. I. J. Hochmair-Desoyer and E. S. Hochmair, ed. Advances in Cochlear Implants. Manz Wein 1994; 326-332.
2. Shiroma, M., T. Kikuchi, A. Kawano, M. Suzuki and K. Kaga. Perception of music by cochlear implantees. http://www.rti.org/ciap97.pr-uu.htm, 1997.
3. Whitford, L. A., P. M. Seligman, P. J. Blamey, H. J. McDermott and J.F. Patrick. Comparison of current speech coding strategies. Adv. Otorhinolaryngology 1993; 48:85-90.
4. Pijl, S. and D. W. F. Schwarz. Melody Recognition and musical interval perception by deaf subjects with electric pulse trains through single cochlear implant electrodes. J. Acoust. Soc. America. 1995; 98:2 Pt 1 August: 886-895.

5. McDermott, H. J. and C. M. McKay. Musical pitch perception with electrical stimulation of the cochlea. J. Acoust. Soc. America. 1997; 101:3 March: 1622-1631.
6. McKay, C. M., H. J. McDermott and G. M. Clark. Pitch percepts associated with amplitude-modulated current pulse trains in cochlear implants. J. Acoust. Soc. America. 1994; 96:5 Pt 1 Nov.: 2664-2673.
7. McDermott, H. J. and C. M. McKay. Pitch Ranking with non-simultaneous dual-electrode electrical stimulation of the cochlea. J. Acoust. Soc. America. 1994;96;1 July:155-162.
8. Eddington, D. K., W. H. Dobelle, D. E. Brackman, M. G. Mladejovsky and J. L. Parkin. Auditory Prostheses research with multiple channel intracochlear stimulation in man. Annals of Otol Rhin. 1978; 87:Sup 53: 5-39.
9. Townshend, B., N. Cotter, D. V. Compernolle and R. L. White. Pitch perception by cochlear implant subjects. J. Acoust. Soc. America. 1987; 82:1 July: 106-115.
10. Pijl, S. Pulse rate matching by cochlear implant patients: Effect of loudness randomization and electrode position. Ear and Hearing Research 1997; 18:4: 316-325.
11. Dorman, M.F., M. Smith, Smith, L. and J.L. Parkin. The pitch of electrically presented sinusoids. J. Acoust. Soc. America. 1994; 95:3 March: 1677-1679.
12. Collins, L. M., T. A. Zwolan and G. H. Wakefield. Comparison of electrode discrimination, pitch ranking and pitch scaling data in postlingually deafened adult cochlear implant subjects. J. Acoust. Soc. America. 1997; 101:1 Jan: 440-455.
13. Busby, P. A., L. A. Whitford, P. J. Blamey, L. M. Richdarson and G. M. Clark. Pitch perception for different mode of stimulation using the Cochlear multiple-electrode prosthesis. J. Acoust. Soc. America. 1994: 95:5 Pt 1 May:2658-2669.