Spectral Profile Analysis in Cochlear Implant Listeners

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Introduction

Profile analysis, the discrimination of different spectral shapes, is necessary for tasks like vowel discrimination, musical instrument identification, and sound localization in the median plane (front-back, up-down). This study investigated whether listeners using cochlear implants (CIs) can perform a spectral profile analysis. Profile analysis might be difficult in CI listeners because the implanted electrode array produces relatively large current spreads in the cochlea and there are often interactions between the electrodes, yielding a much coarser spectral resolution than that accessible to normal hearing (NH) individuals.

Methods

Six CI listeners using 12-electrode implants participated in this study. First, an equal-loudness background was found for each listener. The background had an equal loudness for each electrode and a comfortable loudness when all 12 electrodes were stimulated in an interleaved order at 1515 pulses per second.

In the first experiment, listeners discriminated a stimulus with a flat background from a stimulus with a spectral peak or notch on an otherwise flat background. The peak or notch were presented at three different tonotopic places (low: electrodes 4-6, mid: 7-9, or high: 10-12) and three different bandwidths (1, 2, or 3 electrodes). Conditions without and with overall level roving were tested. Level roving was performed in current units (cus), where 1 cu is equivalent to approximately 7.7 μA. The roving ranges were 10-, 20-, and 30-cus. Intensity discrimination data was also taken (called band only). Overall level roving and intensity discrimination data can be used to determine if listeners are truly performing a profile analysis.

In the second experiment, listeners discriminated a stimulus with a peak or notch from a stimulus with a higher peak or deeper notch. Two places were tested (low and high), the bandwidth was fixed at two electrodes, and overall level roving was not included. The height of the reference peaks and the depth of the reference notches were measured with respect to the background and this difference is called the band level re: background (BLB). This experiment has the advantage over the first experiment that it may limit the amount of energetic masking from channel interactions.

Results

Figure 1 shows the results for the first experiment with just-noticeable differences (JNDs) plotted as a percentage of the dynamic range ($\%_{DR}$). The data for the peaks show that overall level roving significantly increased the JNDs ($p < 0.0001$). There was no significant difference between the peak data without roving and the band-only data ($p = 0.51$) and these data were significantly correlated ($p < 0.0001$).

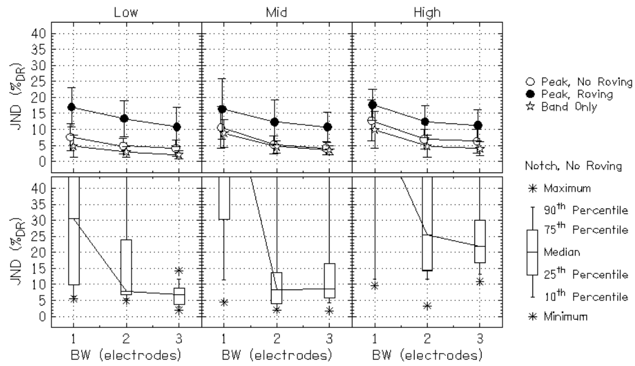

Figure 1: Just-noticeable differences (JNDs) in $\%_{DR}$ for peaks (top row) and notches (bottom row). Not all of the notches could be measured. Therefore a box-and-whisker plot was used for the notches without roving. The notches with roving were not plotted because only a handful of JNDs were measurable. The roving range was 10 cu for the conditions with roving.

Notches were significantly more difficult to detect than peaks ($p < 0.0001$). All of the peaks could be measured but only 69% of the notches without roving and 13% of the notches with roving could be measured. There was a significant effect of place ($p < 0.0001$), the high place being worse than the low and mid places. There was also a significant difference between BW = 1 and 2 electrodes ($p < 0.001$) but not between BW = 2 and 3 ($p > 0.05$).

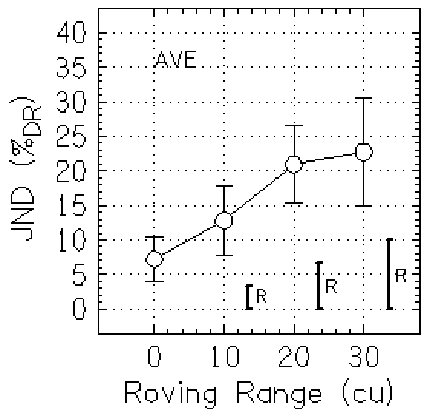

Figure 2: JNDs for larger roving ranges. The bars show 24% of the roving range, above which the listener could have used only intensity discrimination to perform the task.

Figure 2 shows data for larger roving ranges. The stimulus bandwidth was fixed at two electrodes and the place was fixed at high. JNDs increase for increasing roving range. All of the data points are larger than 24% of the roving range. Any JNDs above the bar can be achieved solely by using intensity cues, not profile analysis [1].

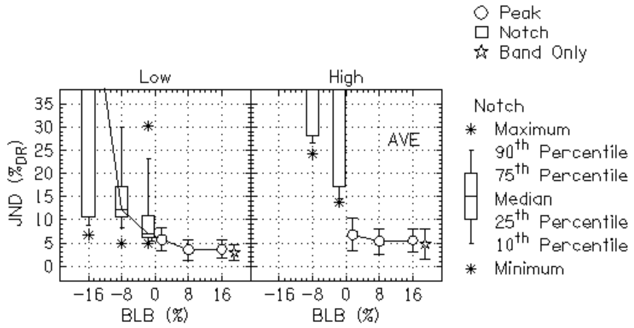

Figure 3: JNDs for the discrimination of higher peaks and deeper notches as a function of the band level re: background (BLB).

Figure 3 shows data for the second experiment, the discrimination of different peak heights or notch depths. For the peaks, the JNDs significantly decrease for increasing BLB ($p < 0.005$). However, there was no difference between the peak data and band-only data ($p > 0.5$). For the notches, the deeper the notch, the higher the JNDs and the fewer the number of measurable notches.

Discussion and Conclusion

Several methods were used to determine if CI listeners are able to perform a profile analysis. Two methods that to determine if listeners are performing a profile analysis are: 1) a small effect of overall level roving and 2) profile analysis JNDs are smaller than intensity discrimination JNDs. In the first experiment, there was a large increase in JNDs when level roving was added. In fact, even with larger roving ranges, the JNDs were well above the theoretical limit where intensity discrimination can be solely used. In both the first and second experiments, JNDs were always larger than intensity discrimination JNDs. This is slightly surprising as the peaks for the second experiment should have limited the across-channel interference and energetic masking, being separated from the background. Either there is still some masking occurring or listeners are only using intensity discrimination to perform the task.

Hence, there is no conclusive evidence that CI listeners can perform a profile analysis, our results agreeing with the other previous study on profile analysis in CI listeners [2]. We do know that CI users do perform some form of profile analysis as they can discriminate vowels very well; understanding speech is the primary reason for the existence of CIs. It may be possible that CI listeners cannot utilize spectral features at higher tonotopic places, which would be important for sound localization cues. Nevertheless, many of the same effects were seen in a similar study performing the same experiments in NH listeners [3], such as peaks being easier to detect than notches and higher tonotopic places yielding higher JNDs.

One problem with this study is that the level roving was performed in cus, rather than following loudness curves. Roving in cus may have drastically changed the background from equally-loud and flat, adding a large amount of uncertainty for the listeners. It may be that the increases in the JNDs were due to mostly this. Therefore, further experiments should be done where loudness curves are measured for each electrode and the background is better controlled. An added advantage of using loudness curves is that additional shapes (slanted spectra, alternating up-down components, etc.) can be used [4], which can produce lower JNDs and may show that CI listeners can perform a profile analysis.

Literature

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