Cochlear Implants

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Introduction

The top panel of Figure 1 shows a schematic diagram of the normal peripheral auditory system. The ear canal and ossicles (small bones) of the middle ear transmit acoustic signals to the cochlea where they produce a travelling wave moving from base to apex along the basilar membrane. Displacement of a segment of the basilar membrane increases the likelihood that the nerve fibers innervating hair cells coupled to that segment will elicit spikes. The structural properties of the basilar membrane result in a maximal displacement for high frequencies at the cochlea's base and for low frequencies at the apex. As a result, the spectral content of an acoustic stimulus is represented by an array of nerve-fiber responses where the highest-frequency components are coded by fibers innervating hair cells at the base and the lowest frequency components at the apex.

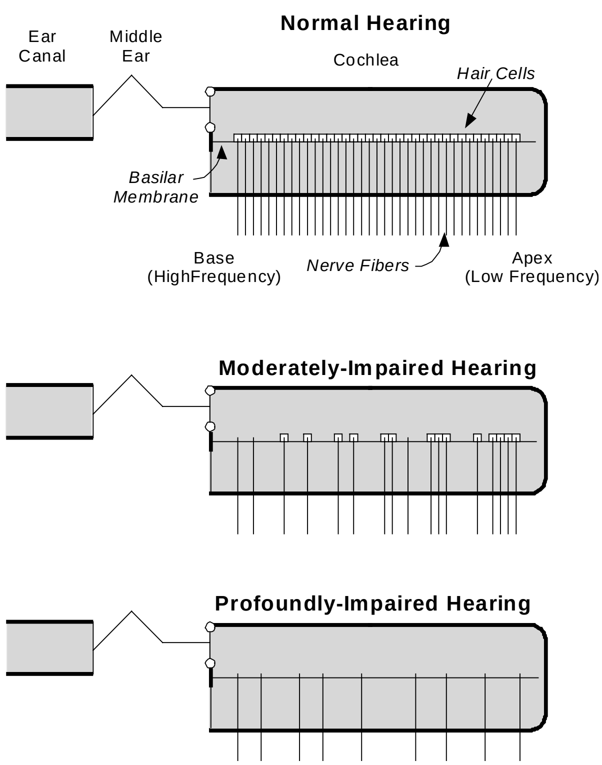

Figure 1. Schematic diagrams of the peripheral auditory system for cases of normal, moderately-impaired and profoundly-impaired hearing.

The middle panel of Figure 1 represents the case of moderate hearing impairment where some hair cells and nerve fibers have been destroyed. Such an impairment can result from a number of causes like bacterial or viral infection, genetic programming and acoustic trauma. When the number and distribution of undamaged hair cells and nerve fibers support sufficient residual hearing, a hearing aid that amplifies the acoustic signal can provide a good deal of benefit.

Unfortunately, this is not the case for the profoundly impaired. As depicted in the bottom panel of Figure 1, few hair cells are available to excite the remaining nerve fibers and amplification is ineffective.

Cochlear implants are devices designed to use electric stimulation of the remaining auditory-nerve fibers to restore a measure of hearing to the profoundly impaired. The basic structure of the device is diagrammed in Figure 2. An array of electrodes (unfilled circles) are surgically implanted in the cochlea and connected to a sound processor. The sound processor (typically DSP-based) is programmed to translate the output of the microphone into electric stimuli delivered to the implanted electrodes. The number of processing and stimulation channels range from 4 to 24.

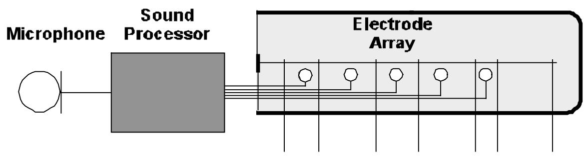

Figure 2. Schematic diagram of a cochlear implant system.

Evidence is accumulating to support the hypothesis that today's electrode systems are not be capable of providing more than six or eight channels of effective information. Studies that systematically increase the number of analysis channels and their associated electrodes show increasing performance from one to approximately seven channels but little, if any, additional benefit to reception in quiet beyond this number (e.g., Holmes, Kemker et al. 1987; Dorman, Dankowski et al. 1989; Lawson, Wilson et al. 1993; Lawson, Wilson et al. 1996; Brill, Gstottner et al. 1997; Fishman, Shannon et al. 1997; Kiefer, von Ilberg et al. 2000). One interpretation of these results is that as the number of electrodes/channels increases, the distance between stimulating electrodes decreases and this increases the cross-talk or interaction between electrodes. It is assumed that these interactions distort the information presented to the brain and limit the theoretical benefit of increasing the number of analysis channels. The measurements described below were designed to test this assumption by determining whether speech reception is negatively correlated with electrode interaction in 11 cochlear-implant subjects using 8-channel sound processing strategies.

Methods

An adaptive (one-up, two-down), three-alternative, forced-choice procedure (Levitt 1971) was used to measure the threshold (THR) of a test electrode in three stimulation conditions: the test electrode stimulated alone (THR_T); the test electrode stimulated in the presence of an in-phase, below-threshold, simultaneous stimulus delivered to a neighboring masker electrode (THR_{TpM}); and the test electrode stimulated in the presence of an out-of-phase, below-threshold, simultaneous stimulus delivered to the neighboring masker electrode (THR_{TmM}).

All stimuli (test and masker) were 300ms, biphasic pulse trains (76.9 us/phase, 812 pps). The test stimulus was delivered to electrode #4 (monopolar configuration) of the eight-electrode array that is part of the Clarion implant system. The masker stimuli were presented to neighboring electrodes positioned 2 mm from the test electrode (e.g., Clarion electrodes #3 and #5).

Each masker electrode's threshold was measured (THR_M) and the masker level (ML) determined for each subject by selecting the lowest of the THR_T and THR_Ms measured in that subject (THR_{min}), and setting $ML = 0.8*THR_{min}$. An interaction index (II) was computed for each masker electrode/configuration using the following relationship[1]:

$$II = (THR_{TmM} – THR_{TpM})/(2*ML).$$

The interaction indices measured for the test/masker combinations in each subject were averaged to give a single interaction index for each subject.

[1] Note that, theoretically, II varies from 0 to 1. In the case of no interaction, $THR_{TmM} = THR_T$, $THR_{TpM} = THR_T$, and $THR_{TmM}–THR_{TpM} = 0$. In the case of maximum interaction where the influence of the masker is as if the masker stimulus is delivered directly to the test electrode, $THR_{TmM} = (THR_T+\mathrm{ML})$, $THR_{TpM} = (THR_T-\mathrm{ML})$, and $THR_{TmM}–THR_{TpM} = 2*\mathrm{ML}$.

Speech reception was measured using a single-syllable word test. The subject is seated in a sound-isolated room and the 50 single-syllable words of the NU6 list [e.g.,Owens, 1985 #59] are played in sequence to the subject from audio tape (no speechreading cues). The subject's task is to repeat each of the words he/she hears. From these results, an overall score is computed (percent correct).

Results

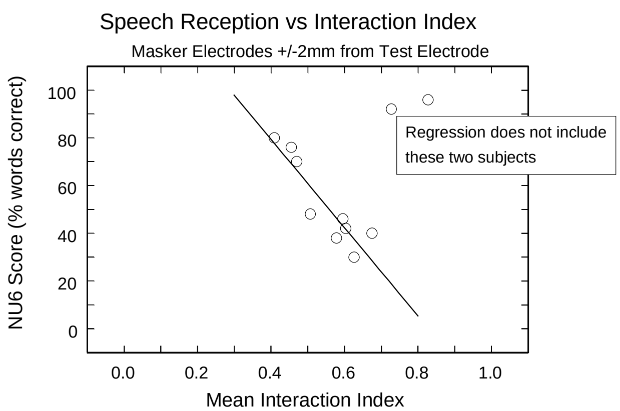

Figure 3. Scatter plot of single-syllable word recognition as a function of mean Interaction Index for 11 subjects using the standard Clarion implant system with 8-channel sound processing systems. The line represents a linear regression on the results from all but the two subjects noted.

Figure 3 plots the single-syllable word score as a function of the mean Interaction Index (mean *II*) for the 11 subjects tested. These data show a strong negative correlation (r = 0.91) between speech reception and mean *II* for 9 of the subjects tested. However, the two subjects with the highest mean *II*s also post the best speech-reception scores. We continue to search for factors that account for the performance of these two subjects.

The assumption that electrode interaction adversely impacts speech reception led to the Clarion HiFocus electrode system that is designed to reduce interaction by positioning the electrode contacts closer the excitable tissue. While these devices have not been implanted long enough for reliable measures of speech reception to be made, we have made psychophysical measures of electrode interaction.

The bar graph shown in Figure 4 plots the mean *II* for the 11 subjects implanted with the standard Clarion electrode and for 7 subjects implanted with the new HiFocus electrode. These results show that the mean *II* is significantly smaller for the HiFocus than for the standard electrode system (t-test, p<0.0001).

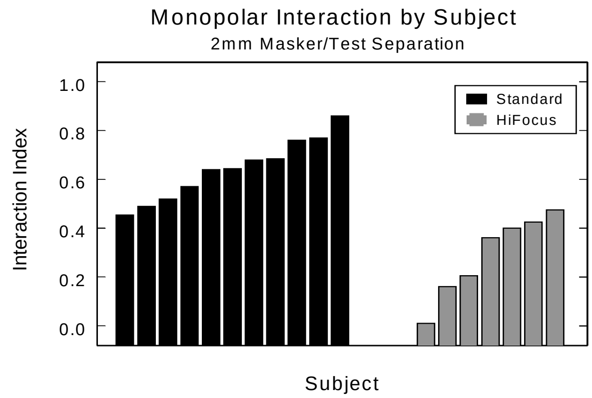

Figure 4. Bar graph presenting the mean Interaction Indices measured for the 11 subjects from Figure 3 and 7 subjects implanted with the Clarion HiFocus electrode system.

Conclusions

While the results from two of the 11 subjects represented in Figure 3 are not consistent with the hypothesis that speech reception is negatively correlated with electrode interaction, the strong negative correlation found in 9 of the subjects using the standard electrode indicates electrode interaction may be an important factor for some implantees. This, together with the significant reduction of interaction in the 7 subjects using the HiFocus electrode, provide a strong motivation for examining speech reception in the HiFocus subjects using 8-channel sound-processing strategies. Given the relatively low *II*s of the HiFocus subjects, we also plan to explore whether increasing the number of analysis channels from 8 to 16 will improve performance for these subjects.

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