Loudness Balance between Acoustic and Electric Stimulation by a Patient with a Multichannel Cochlear Implant

Michael F. Dorman, Luther Smith, James L. Parkin

Abstract

Estimates of loudness balance were obtained for acoustically and electrically presented 250 Hz sine signals from a patient who uses the Ineraid multichannel cochlear implant. Acoustic and electric loudness matching was possible because the patient evidenced a 25 dB HL threshold at 250 Hz in his nonimplanted ear. The level of the electrical stimulus in microamperes required for a balance of loudness grew linearly with equal increments in decibels for the acoustic stimulus. These data, in concert with the very limited data from previous studies, provide a rationale for using a logarithmic transformation of acoustic to electric intensity in signal processors for cochlear implants.

One of the critical factors in the design of a cochlear prosthesis is the transformation of acoustic signal amplitude to electrical signal amplitude. This factor is critical because signal processing must produce electrical signals that mirror the loudness of acoustic signals presented to the cochlea.

One set of relevant data is that which compares the loudness of acoustic signals in a hearing ear to the loudness of electrical signals in an implanted ear. Data of this kind are extremely limited due to the criteria for implantation: patients must have profound hearing losses bilaterally. Thus, the entire data set has been obtained from one unilaterally deafened patient with electrodes in the cochlea (Eddington, Dobelle, Brackmann, Mladejovsky, & Parkin, 1978), and from three unilaterally deafened patients with an electrode on the cochlear nucleus (Zeng & Shannon, 1992). The patient tested by Eddington et al (1978) was a "preclinical trials volunteer" and, thus, did not have to meet the later, more stringent Food and Drug Administration requirements for implant patients.

Zeng and Shannon (1992) have reviewed these data and have found, as Eddington et al (1978) originally reported, a linear relationship between acoustic decibels and electric signal amplitude. Zeng and Shanon noted that the inference to be drawn from these data for implant design is that the function that maps acoustic input to electric output should be logarithmic.

In September 1990, author J.L.P. implanted the Ineraid electrode array in the right cochlea of a patient (MK) who had 0% speech identification scores bilaterally. Hearing thresholds in MK's nonimplanted ear were less than 50 dB HL for frequencies under 500 Hz. Given the presence of only a mild hearing loss at 250 Hz, and given only one other report on loudness matching by a cochlear implant patient, we sought to match the loudness of 250 Hz signals presented to the hearing and implanted ears.

Method

Subject

The patient (MK) was 70 years old at the time of testing, which was 21 months after surgery. His hearing began to deteriorate bilaterally in 1945 from unknown causes. At the time of surgery, September 27, 1990, he evidenced no speech understanding in either ear at 105 dB HL. At that time, the thresholds in his to-be-implanted ear were 30 dB HL at 250 Hz and 75 dB HL at 500 Hz. He had no response to frequencies higher than 500 Hz. In his nonimplanted ear, the threshold at 250 Hz was 25 dB HL; the threshold at 500 Hz was 50 dB HL. He had no response to frequencies of 1 kHz and above. The patient had tried and rejected a hearing aid.

At the time of this experiment, the 250 Hz threshold in his nonimplanted ear was 25 dB HL. Uncomfortable loudness was reached at 110 dB HL. For electrode 1, the 250 Hz (sine) threshold was 26 µA and the uncomfortable loudness level was 130 µA. For electrode 2, the threshold was 28 µA and the uncomfortable loudness level was 145 µA.

Stimuli

The acoustic 250 Hz sine signal was generated by an Amplaid 207 audiometer and delivered via a TDH-39 headphone. The audiometer was calibrated before data collection.

The electrical 250 Hz sine signal was generated by an Ineraid Electrode Analyzer and delivered

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Arizona State University, Tempe, Arizona (M.F.D.); University of Utah School of Medicine, Salt Lake City, Utah (M.F.D., J.L.P.); and Sinai Samaritan Medical Center, Milwaukee, Wisconsin (L.S.).

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through an optically isolated, constant current source. The signal level was controlled by a potentiometer. Signal levels were monitored on-line by a Tektronix 2211 digital oscilloscope and were measured peak to peak. The monitoring system was optically isolated from the patient and from the signal generation system.

The patient reported that the acoustic 250 Hz signal sounded "pure" at all signal levels. This was not the case at any level for the electrical 250 Hz signal (see also Eddington et al, 1978). MK reported that when the electrical signal was presented to his electrodes, he experienced a sound with two perceptual components—one low-pitched and dominant and the other high-pitched and less dominant ("farther away"). [We suppose that the two components of the electrically elicited percept reflect the output of periodicity pitch and place pitch mechanisms (again, see Eddington et al, 1978).] When the electrical signal was presented to more basal electrodes, the pitch of both the low and high components increased. MK reported that loudness matching between his two ears was easiest when signals were presented to his two most apical electrodes because the low-frequency percept was similar to that elicited by the acoustically presented signal.

Procedure

The acoustic signal was directed to the patient's hearing ear for 1.5 sec. At signal termination, the experimenter activated, by button press, the electrical signal for 1.5 sec. The patient was instructed to first indicate when the electrical signal was softer than the acoustic signal and then was instructed to indicate when the signal was louder than the acoustic signal. Finally, the patient was asked to indicate when the two signals were equally loud. The level of the electrical signal was varied by the experimenter in response to the patient's responses.

Loudness matching was obtained for signals presented to the patient's two most apical electrodes. The electrically delivered signals were matched to acoustic signals presented at 40 to 100 dB HL in 10 dB steps. The electrodes were tested in the order of 1 (most apical) to 2. The order of HL levels was randomized for each electrode tested. Two loudness matches were obtained for each HL-electrode combination.

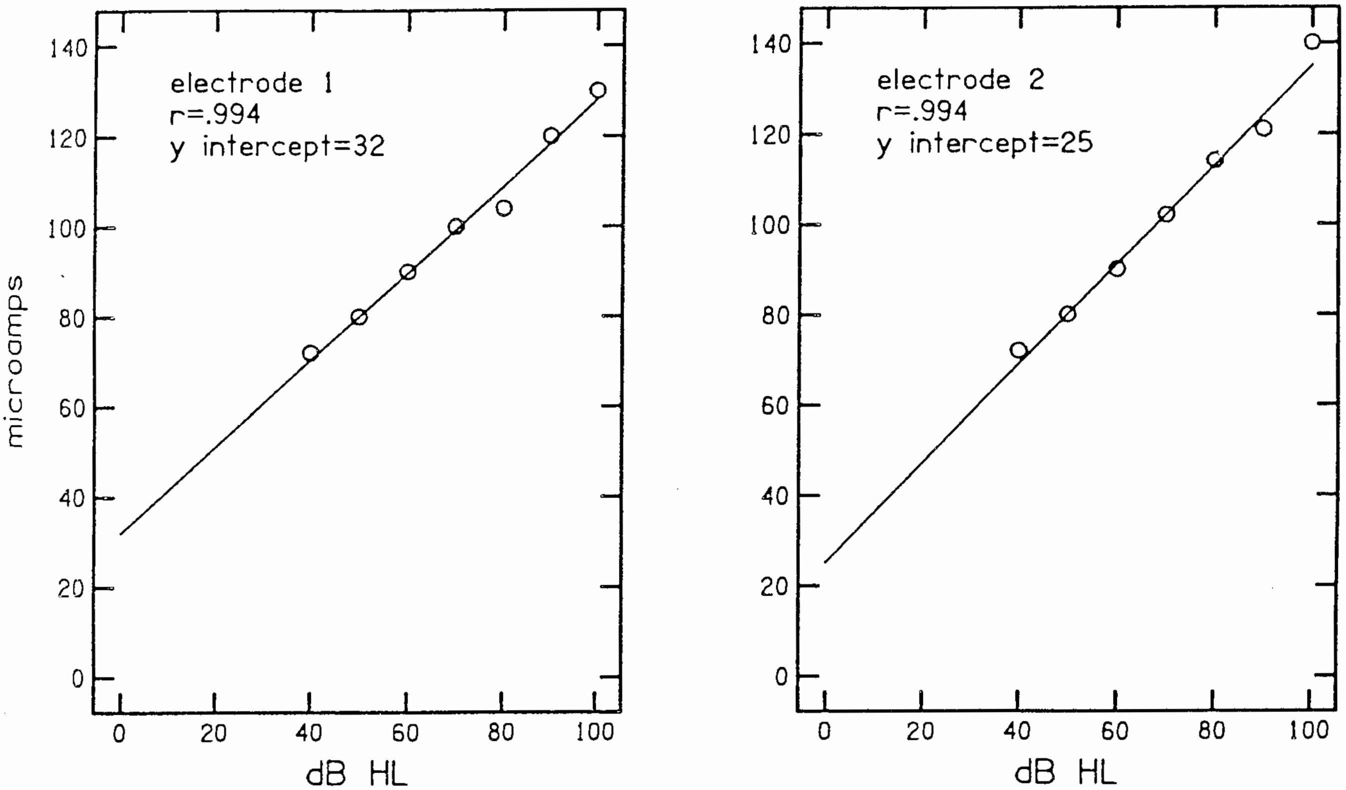

Figure 1. Loudness balance between acoustic and electrical stimulation for patient MK. The data points indicate the points of subjective equality for acoustically delivered and electrically delivered signals.

Loudness matches with stimulation directed to the two more basal electrodes were not obtained because the patient indicated that the difference in perceived pitch between the two ears was large. The patient indicated that this factor changed the subjective nature of the task.

Results

The averaged loudness matching data are shown in Figure 1. For signals presented to electrodes 1 and 2, linear relationships were found for the loudness of acoustic signals expressed in decibels and for the loudness of electrical signals expressed in microamps. The Pearson correlation coefficient for both conditions was 0.994.

The Y-intercept for the straight line function fit to the data from electrode 1 was 32 µA. The objectively determined threshold was 26 µA. The Y-intercept for the straight line function fit the data from electrode 2 was 25 µA. The objectively determined threshold was 28 µA.

Discussion

Our loudness matching results are consistent with the results from the single cochlear implant patient reported by Eddington et al (1978) and from the three cochlear nucleus implant patients reported by Zeng and Shannon (1992). In each case, a linear relationship has been found between the loudness of signals expressed in acoustic decibels and the loudness of electrical signals expressed in microamps. As Zeng and Shannon note, these data provide a rationale for using a logarithmic transformation of input signal amplitude in order to achieve appropriate levels of signal loudness for implant patients. Indeed, a portion of the improvement in speech understanding achieved by Ineraid patients when fitted with the "continuous interleaved sampler" processor of Wilson et al (1991) may be due to the logarithmic transformation of signal amplitude provided by the continuous interleaved sampler processor.

References

Eddington D, Dobelle W, Brackmann D, Mladejovsky M, and Parkin J. Auditory prosthesis research with multiple channel intracochlear stimulation in man. Ann Otol Rhinol Laryngol 1978;87(Suppl):1–39.

Wilson B, Lawson D, Finley C, Wolford R, Eddington D, and Rabinowitz W. Better speech recognition with cochlear implants. Nature 1991;352:236–238.

Zeng FG and Shannon R. Loudness balance between electric and acoustic stimulation. Hear Research 1992;60:231–235.

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Address reprint requests to Michael F. Dorman, Department of Speech and Hearing Science, Arizona State University, Tempe, AZ 85287-0102.

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