THE MISSING LINK – THE IMPORTANCE OF DIAGNOSTIC AND FITTING STRATEGIES FOR CLINICAL AMELIORATION OF HEARING LOSS USING DIGITAL HEARING-AID TECHNOLOGY

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Abstract

A novel approach to fitting hearing aids, successfully deployed on thousands of clients, is described in this paper. Comprehensive diagnostic tests assess the client's ability to process speech and other complex sounds in a wide range of listening environments. These diagnostics are also used to select the most appropriate hearing aid and to tune the device for optimum benefit. The efficacy of this fitting procedure was evaluated in nine subjects. Speech intelligibility was measured in three conditions – quiet (55 dB SPL), moderate speech babble (0 dB S/N) and extreme speech babble (–5 dB) – representative of the real-world conditions encountered by the hearing impaired. The same model digital hearing aid was fit in one of two ways – (1) according to the manufacturer's recommended settings for gain and compression based on the subject's audiogram, and (2) according to Hearing Centers Network's methodology. In quiet, there was a modest, but reliable difference in speech intelligibility performance between the two fitting strategies – 83% correct (s.d. = 9.7%) for the HCN fitting versus 62% correct (s.d. = 14.6%) for the manufacturer's fitting. In noise, the disparity between fitting procedures increased dramatically. At 0 dB S/N, intelligibility was 77% correct (s.d. = 14.8%) for the HCN prescription and 43% correct (s.d. = 13.9%) for the manufacturer's fit. At –5 dB S/N, intelligibility was 64% correct (s.d. = 18.8%) for the HCN prescription and 16% correct (s.d. = 11.6%) for the manufacturer's recommended fit. Intelligibility was superior using the HCN fit for all subjects under all conditions tested. These data suggest that the fitting formulations prescribed by manufacturers focus on understanding speech in quiet, but are ill suited to backgrounds (such as speech babble) posing the greatest challenge to the hearing impaired. In contrast, HCN's fitting methodology provides relatively high (and stable) intelligibility for all subjects under comparable conditions.

Introduction

Currently, most hearing-impaired individuals derive only limited benefit from hearing aids. Typically, hearing aids provide the greatest benefit in quiet listening conditions, but are not particularly effective in noisy environments. Unfortunately, it is noisy backgrounds, such as those encountered in restaurants and other places of intensive social interaction, that provide the greatest challenge to the hearing impaired. In such circumstances, hearing-impaired individuals rarely wear their aids even though it is precisely these conditions under which the hearing aid should, in principle, provide the greatest benefit.

It is the thesis of this study that current-generation hearing aids are capable of providing substantially greater benefit if only the methods by which they are fit were substantially revised. In particular, we demonstrate that the ability to understand spoken language in noisy backgrounds improves dramatically when the fitting procedure is adapted to take into account more than just factors related to audibility and loudness.

These other factors are derived from a comprehensive diagnostic evaluation of the client's hearing-related communication deficits (of which audibility and loudness are just two). This diagnostic evaluation is essential for customization of the selection and fitting of the hearing aid to the subject's unique auditory-cognitive profile. This information can be effectively used to adjust the hearing aid's fitting over the lifespan of the client.

Basic Methodology

Hearing-aid manufacturers typically provide "first fit" prescriptions for adjusting the gain of the aid across the acoustic spectrum. These first-fit formulations are derived largely from audibility tests and are based on "targets" specified by the National Acoustics Laboratory in Australia (NAL-NL1), or other comparable formulations. These targets are derived from estimates of the subject's hearing threshold obtained in a quiet setting (usually in a sound-proof booth). It is generally assumed that such audibility data collected in quiet is the most appropriate basis for adjusting the hearing aid's gain pattern even when the goal is to improve the client's ability to understand speech in noise. It is assumed that sophisticated signal processing and directional microphone technology will compensate for whatever the target formulations miss.

Hearing-aid manufacturer algorithms routinely use these targets to set the channel gain pattern. In this study, we compare the intelligibility of monosyllabic words, across a range of listening conditions: (1) unaided performance (2) hearing aids fit according to the NAL-NL1 targets, and (3) hearing aids fit in accordance with Hearing Centers Network's comprehensive diagnostic metrics.

The most advanced manufacturer's "first fit" prescription (designed for the highly experienced hearing-aid user) was selected for this study, with options chosen to accommodate the characteristics of each subject's personal earmold. The HCN prescription was derived from methodology described previously (Magilen, 1991, 1995), but modified to exploit recent advances in signal-processing algorithms and directional microphone technology.

The spoken material was derived from the C.I.D. W-22 word lists and were embedded in a common carrier phrase. They were presented over loudspeakers (Bose Lifestyle Powered Speech System) at an overall sound pressure of either 55, or 60 dBA in a sound-attenuated room. The subject was seated in a comfortable chair 1 m from the loudspeakers. Speech babble was presented over loudspeakers (Cyber Acoustics CA-3095) situated underneath a desk. These speakers were configured to make the babble sound as if coming from all around the room in order to simulate realistic listening environments. The subject was instructed to repeat the final word of each sentence. Each response was manually recorded and scored. Twenty phrases were presented to each subject in each condition.

The subjects were nine clients of Hearing Centers Network who volunteered their time. They were all wearers of binaural Siemens Signia hearing aids, and ranged in age between 70 and 86 years. Binaural hearing loss ranged between 31 and 68 dB HTL PTA. Speech discrimination scores ranged between 65 and 100% for the subject's better ear.

The speech material was presented in three separate listening conditions. In the first, the sentences were presented without any background interference ("Quiet") at a level of 55 dbA. In the second, the noise background was multi-talker speech babble presented at the same overall sound pressure level as the speech (i.e., 60 dBA – "0 dB SNR"). Finally, the same speech babble material was presented at a level 5 dB higher than the speech (i.e., 60 dBA babble, 55 dBA speech – "–5 dB SNR").

Intelligibility Results

Intelligibility for unaided listeners ranged between 0 and 70% correct in the Quiet listening condition. Three of the nine subjects were unable to correctly report any of the words. The mean intelligibility score was 22% (Figure 1).

The average intelligibility for the nine subjects was 62% correct (s.d. 14.6%) using the NAL-NL1 targets and 83% (s.d. = 9.7%) using the Hearing Centers Network settings. In no instance did a subject do better with the NAL-NL1 settings than with the HCN formulation. In four of the nine subjects the HCN settings achieved a substantially better result (i.e., an intelligibility score that was at least 30% higher) (Figure 1).

In the 0-dB SNR background noise condition, intelligibility was uniformly poor in the unaided condition. Six of the nine subjects were unable to correctly report any of the key words presented (Figure 2). Intelligibility for the other three listeners ranged between 20

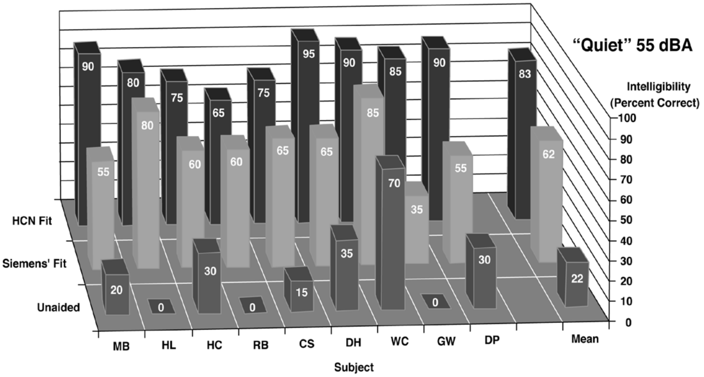

Figure 1 Intelligibility for nine subjects (and the mean of their data) on C.I.D. W-22 word lists under three separate conditions: (a) without the use of a hearing aid ("unaided"), (b) using binaural BTE hearing aids fit according to the NAL-NL1 specfication use by the manufacturer ("Siemens' Fit"), and (c) using the same binaural BTE hearing aids programmed according to the formulation developed by Hearing Centers Networks ("HCN Fit"). The material was presented under "Quiet" listening conditions (i.e., no background noise) at a sound pressure level of 55 dBA.

and 40% correct. Overall, the average intelligibility of the nine subjects in the unaided condition was 9%. With the NAL-NL1 targets, intelligibility improved by 43% on average (s.d. = 13.9%). No subject was able to report more than 65% of the words correctly. In contrast, the same subjects using the HCN fitting, were able to report (on average) 77% (s.d. = 14.8%) of the words correctly. No subject scored less than 55% words correct, and five subjects out of nine correctly reported 80% of the words or better (Figure 2).

In the most difficult listening condition (–5 dB SNR), the contrast between the NAL-NL1 and HCN fittings are even more dramatic. Unaided performance is 0% for all subjects (Figure 3). The average proportion of words correctly reported using the NAL-NL1 fittings is 16% (s.d. = 11.6%), while intelligibility was 64% (s.d. = 18.6%) for the HCN fitting. In no instance was a subject able to correctly report more than 35% of the words using the NAL-NL1 fitting. Five of the nine subjects reported 70% or more of the words correctly using the HCN fitting (Figure 3).

Overall, the subjects did as well or better using the HCN fitting in the noisiest listening condition (–5 dB SNR) as they did using the NAL-NL1 fitting **in quiet**. Only a modest degradation of intelligibility was exhibited across listening conditions for the HCN fitting. For five of the nine subjects, there was virtually no reduction in intelligibility between the Quiet and –5 dB SNR conditions.

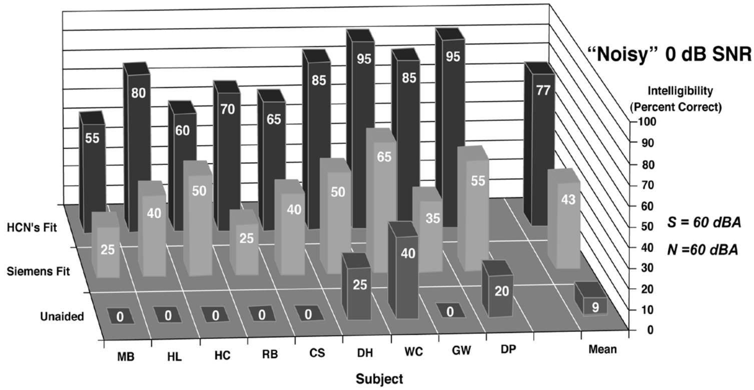

Figure 2 Intelligibility data comparable to those illustrated in Figure 1. The material was presented under "Noisy" listening conditions (i.e., 0 dB signal-to-noise ratio) in which both the speech signal and the background noise (speech babble) were presented at 60 dBA.

The Importance of Channel Gain Across the Frequency Spectrum and Its Relation to Individual Differences

A variety of factors are usually selected by the manufacturer for successful fitting of a hearing aid to achieve the target prescription.. These include hearing thresholds, compression time constants, directional microphones, as well as signal processing germane to voice activity detection and the decision of whether to use a volume control or not. These factors can be as important as the control of gain across the frequency spectrum for achieving optimum intelligibility benefit.

The difference in gain between the NAL-NL1 targets and those used by HCN are shown in Figure 4. In the upper portion of the figure are shown the **raw** gain disparities, while the absolute gain differences are shown at bottom. These data are derived from 9 subjects used in the earlier part of this study. A consistent difference is the amount of gain provided to the high-frequency portion of the spectrum. The HCN fitting delivers more energy to the high-frequency portion of the spectrum, particularly at low and moderate sound pressure levels. In this sense, the gain settings are highly dynamic and take advantage of the non-linear nature of acoustic transduction. Overall, there is a 10-dB difference between the NAL-NL1 and the HCN fittings. The 10-dB average disparity in the gain settings is significant.

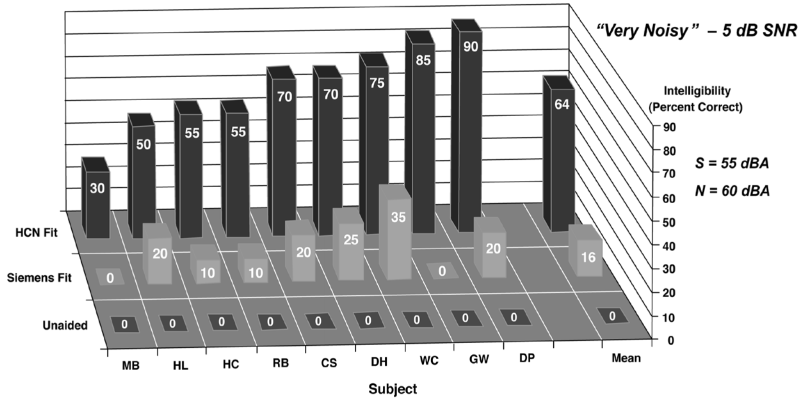

Figure 3 Intelligibility data comparable to those illustrated in Figure 1. The material was presented under "Very Noisy" listening conditions (i.e., –5 dB signal-to-noise ratio) in which the speech signal was presented at 55 dBA and the background noise (speech babble) was presented at 60 dBA.

The Importance of Hearing Aid Parameters other than Gain and Their Relation to Individual Differences in Intelligibility Benefit

Under certain circumstance, optimum benefit in intelligibility depends on factors other than gain settings. For example, subject DH, received a difference in average overall positive gain of only 3 dB, yet exhibited a 45% improvement in intelligibility relative to the NAL NL1 fitting. Subject GW had a bilaterally symetrical sensorineural hearing loss, yet required radically different compression characteristics in each ear to achieve optimum benefit. Subject MB, required a combination of signal processing algorithms and compression characteristics across frequency to achieve an improvement of 30% over the manufacturer's first fit settings.

Discussion

The data suggest that the "first fit" formulation for fitting hearing aids fails to specify the gain pattern required to obtain optimal intelligibility in quiet and particularly in noisy conditions. Moreover, the manufacturter's settings of compression characteristics, signal processing algorithms and directional microphones often do not adequately compensate for speech comprehension problems particularly in noise. One of the problems with the NAL-NL1 approach is the implicit assumption of a static target. Actually, there is no such

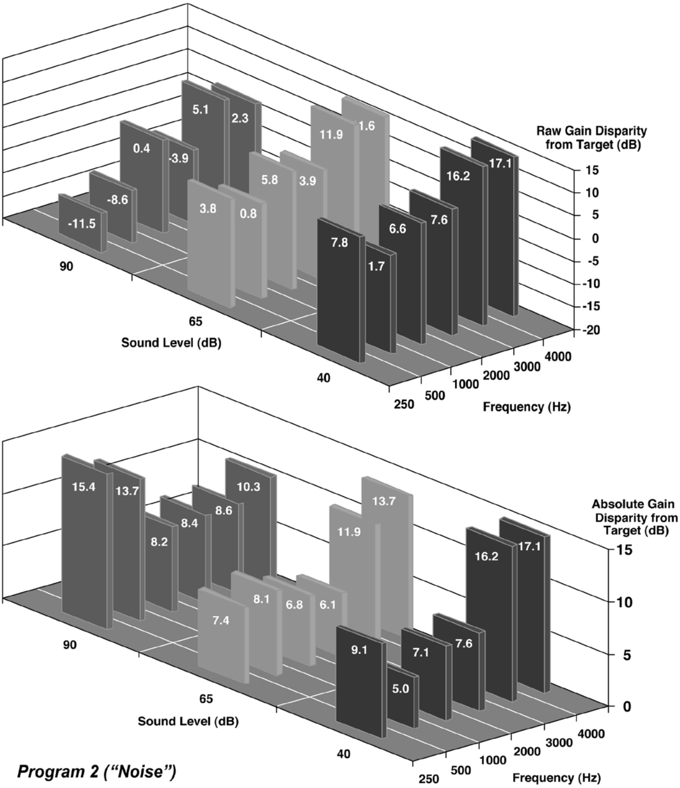

Figure 4 The disparity in hearing aid gain settings between the NAL-NL1 target specifications and those used by Hearing Centers Network based on its comprehensive test battery. The disparities shown are averages across the nine subjects (18 ears) whose data are illustrated in Figures 1 through 3. The gain disparities are shown for three separate sound levels, 40, 65 and 90 dB, across six separate frequencies, 250, 500, 1000, 2000, 3000, 4000 Hz. The upper illustration shows the raw gain disparities (i.e., where both negative and positive differences in gain settings are incorporated into the averages). The lower illustration shows the absolute gain disparities (in which the negative and positive disparities are treated as equivalent for averaging).

thing as a static target with respect to understanding speech in the real world. Speech is a highly dynamic signal and usually occurs in the presence of equally dynamic background conditions (which is often speech as well).

In order to obtain the final fittings for subjects participating in this study, it was necessary to perform between 200 and 400 parametric manipulations per program. Virtually every parameter associated with the NAL-NL1 target, and the manufacturer's compression characteristics, signal-processing algorithms and directional microphones had to be modified. In contrast, most hearing aid practitioners begin and end their fitting with the NAL-NL1 targets. It is little wonder that most clients are not particularly happy with the way in which the hearing aids perform.

The principle underlying the HCN fitting procedure is to deliver dynamically managed energy in a manner most appropriate for the individual client and is tuned to the individual's auditory processing and cognitive capabilities. This is particularly important in noisy conditions. How does one determine where and how the energy should be delivered? This can be achieved by:

(1) Administering diagnostic tests that assess each client's individual auditory-cognitive capabilities and deficits

(2) Performing 200-400 parametric alterations (per program) of the manufacturer's "first fit."

(3) Administering a comprehensive battery of test signals presented over a broad arrange of acoustic environments

(4) Using spectrographic instrumentation to evaluate signal modifications induced by the hearing aid

(5) Evaluating the effect of these modifications on the client's perception of sound and speech comprehension

There are two general types of variable each of which is important to delineate in testing the hearing impaired. One type is observable, the other hidden. The readily observable parameters are (1) audibility, (2) loudness, and (3) intelligibility. The hidden parameters are (1) loudness perception linked to sensory scene analysis, (2) spectral and temporal distortions, (3) spatial distortions and (4) a multitude of cognitive distortions. Such cognitive distortions pertain to the brain's ability to resolve signals in the presence of competing sensory signals and are extremely important for achieving optimum benefit. Conventional fitting procedures focus on the readily observable variables, but usually neglect the hidden parameters. However, for speech intelligibility to be optimized it is essential to fine-tune all of the hearing aid's settings using the hidden parameters.

Individuals vary tremendously with respect to both the hidden and apparent parameters. There is far greater variability among the hearing impaired than is commonly acknowledged. Other sources of variability include the ability to adapt to the hearing aid over time and the ability to exploit dynamic acoustic information across the frequency spectrum and over a range of sound pressure levels. Such variability is difficult (if not impossible) to accommodate within an automatic fitting procedure. Instead, the hearing aid practitioner must customize the fit to the client's unique auditory-cognitive profile.

The most convincing demonstration of an approach's efficacy is customer satisfaction. The official return rate for most hearing aids is ca. 25% (unofficially, the return rates often run as high as 50%). These extraordinarily high return rates imply that many hearing aid users are extremely dissatisfied with their prostheses. Moreover, the official return rates probably understate the problem, as many prospective hearing-aid users don't even bother getting fit because of the technology's less-than-stellar reputation. We estimate that only 10% of the hearing impaired who are capable of deriving substantial benefit from hearing-aid technology currently do so.

The return rate at Hearing Centers Network is less than 3%. Virtually all HCN clients use their hearing aids continuously during the day (Magilen and Gitles, 2001). Moreover, periodic surveys sent to HCN's clients indicate that they are generally happy with their hearing aids. Those few expressing dissatisfaction are asked to come in and have the hearing aid adjusted to alleviate any problems encountered.

Conclusions

Current-generation hearing aids are already capable of improving most hearing-impaired clients' capability to understand speech under a wide range of listening conditions. The problems lie not so much with the technology but rather in the way in which the technology is fit or fine-tuned by the practitioner.

The manufacturer's "first fit" based on the NAL-NL1 specification (or any other standard) is sub-optimal in most conditions. This is because the targets are based on audibility measures in quiet, which rarely provide the appropriate data with which to compute the optimal gain settings across the full range of listening conditions encountered by the client.

The sort of diagnostic tests used to fit hearing aids should be broadened and enhanced to delineate all of the factors affecting the ability to understand spoken language. Audibility and loudness are just two of these factors, yet account for virtually all of the fitting data currently used by most practitioners. Practitioners should be trained far more rigorously than is currently done. Hearing aid fitters should also be capable of efficiently tuning hundreds of parameters within a single fitting session. In some very real sense, the skills required to routinely achieve optimum hearing aid benefit are analogous to those of a highly skilled surgeon. Also required is a radical change in the way in which hearing aid dispensing is practiced. This means improving the training, as well as raising the standards of service provided and broadening the perspective of the field to include cognitive factors in the fitting of hearing aids. Moreover, future signal processing technology needs to be developed that addresses the auditory and cognitive processing problems germane to speech comprehension, especially in noise. Hearing-aid technology should be designed with the fitting process in mind.

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