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Digital technology and clinical practice: The outlook for the future

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INTRODUCTION

Digital technology has made important contributions to the field of audiology. In the past few years the computer has been incorporated into many pieces of equipment that are essential to the practice of audiology. For example, audiometers are now microprocessor-based, the computer is essential to the equipment used to measure the auditory evoked response, and the newer hearing aid measurement systems are computerized, as are probe microphone systems. In some instances, the fact that a clinical instrument is computer-based has little effect on the way clinical testing is done or on clinical management of a case. The fact that an audiometer contains a microprocessor does not necessarily cause a change in the clinical procedures to be used, or even in the manner the procedure is carried out. In other instances, availability of the computer stimulates the development of new methods and procedures that extend clinical resources and improve the ability to provide services to hearing-impaired persons.

Without the capability of averaging a large number of time-locked responses to sound, measurement of the auditory evoked response would not be possible. Averaging could be done using analog equipment, but brain stem audiometry might not have become a viable clinical tool were it not for the computer, which made the procedure truly efficient. Once the technology for measuring auditory evoked potentials became available, its potential for clinical use became evident. It is presently used for identification of hearing loss in difficult-to-test patients and for neuroaudiologic testing. New techniques continue to be developed (e.g., brain electrical activity mapping).

In the case of hearing aid measurement systems, digital technology has made it possible to measure the electroacoustic characteristics of a hearing aid more efficiently. New methods for measuring the output of hearing aids are also feasible because of the special properties of computer-based systems. For example, real-time spectrum analysis of the output of the hearing aid enables the use of a complex stimulus rather than a pure tone stimulus as the test signal. This type of analysis is particularly useful for the measurement of nonlinear hearing aids (e.g., compression aids and "automatic signal-processing" aids). The use of a complex stimulus allows for more accurate measurement of the performance of nonlinear hearing aids in the low frequency region than does the use of a pure tone stimulus. It is expected that new measuring techniques will be developed to further realize the potential of the computer.

Although probe microphones have been used by researchers for many years, clinical use of these microphones is very recent. Computerization makes the calibration of the probe microphone systems simple and efficient. Probe microphone systems enable the clinician to make real ear measurements of the electroacoustic characteristics of the hearing

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aid, rather than relying on coupler measurements. The availability of such systems has been especially helpful to those using prescriptive fitting techniques because they make it possible to verify that the targeted frequency-gain response has been obtained.

The application of digital technology to hearing aids is expected to have a dramatic impact on the potential benefit of amplification systems. The introduction of digital hearing aids and computerized fitting systems will cause major changes in the methods used to dispense hearing aids and should stimulate the development of new diagnostic, prescriptive, and rehabilitative techniques.

THE PAST: ANALOG HEARING AIDS

Until recently, technology was the limiting factor in the design of hearing aids. Indirectly, the limitations of the technology shaped the aural rehabilitation process. The early carbon hearing aids had limited gain, a narrow bandwidth, and a peaky frequency response. Because those hearing aids provided little amplification, only a small portion of the hearing-impaired population—those with mild or moderate hearing loss—could benefit from them. As technology improved, the number of hearing-impaired individuals who could be helped by wearing a hearing aid became larger and more diverse. When the vacuum tube hearing aid was developed, more gain was possible and individuals with severe or profound hearing loss could benefit from amplification. But, even so, narrow bandwidths and irregular frequency responses limited the potential benefit of those hearing aids. Today, hearing aids have a broader bandwidth and a smoother frequency response. Recent improvements in the filtering capabilities of hearing aids have made it possible to provide appropriate amplification for individuals with hearing loss only in the high frequencies, or, conversely, for those with hearing loss only in the low frequencies.

Other improvements in hearing aid technology are making it possible to provide powerful hearing aids in a size that is cosmetically acceptable to the hearing aid user. Improvements in the components of hearing aids are expanding the types of processing possible, as well as increasing the quality of the amplified signal. It seems likely that the next generation of hearing aids will be digital. Already, a combination digital/analog circuit has been incorporated into some hearing aids (4), and several companies are actively researching ways to produce wearable digital hearing aids. How will digital hearing aids differ from the analog hearing aids now available, and how will the availability of digital hearing aids affect clinical practice?

THE FUTURE: DIGITAL HEARING AIDS

In the digital hearing aid, a microprocessor will replace the hardware used to process the signal (e.g., filtering, compression). The analog output of the microphone will be low-pass-filtered to prevent aliasing errors, sampled at discrete intervals, and will be converted to binary form using an analog-to-digital converter. The digital signal will be processed in the manner in which the microprocessor has been programmed. The processed digital signal will then be converted back to an analog signal via the digital-to-analog converter and sent to the hearing aid receiver.

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The first generation of digital hearing aids is likely to be similar to currently available analog hearing aids, with regard to the type of processing that will be done. The major difference between digital aids and the present generation of analog aids will be the degree of control over the parameters of the hearing aid. Because the characteristics of the hearing aid (e.g., frequency response, maximum power output, compression parameters, etc.) will be specified in the software, the constraints imposed by hardware will be eliminated. The characteristics most suitable for an individual hearing aid user can be specified precisely in the software. The audiologist/dispenser will no longer be limited to selecting the best aid from available hearing aid models, but will be able to specify the hearing aid most appropriate for each client.

In the digital hearing aid there will be no need for dispenser-operated potentiometers to set the appropriate filter setting (tone controls), maximum power output, or compression characteristics. Because all of the parameters are specified in the software, it will be possible to obtain the desired electroacoustic characteristics without *post hoc* manipulation of the hearing aid characteristics or of the earmold.

A system for fitting and programming a digital hearing aid has been described by Engebretson et al. (3), which is typical of the system an audiologist might expect to use in fitting digital hearing aids. It consists of a central computer and operator terminal, a second terminal for the patient to use in responding to test stimuli, and the digital hearing aid, which is connected to the central computer via a serial port. The central computer is used to generate test signals that measure the patient's thresholds, most comfortable loudness level (MCL), and the uncomfortable loudness level (UCL). The patient indicates responses to the test signals by using a computer terminal. Responses are tabulated in the central computer, an appropriate hearing aid characteristic is calculated according to a prescriptive method, and the hearing aid parameters are then downloaded to a wearable digital hearing aid. At that point, the digital hearing aid is disconnected from the central computer.

With such a system, the fitting procedure is expected to be less time-consuming than would be a similar procedure using an analog hearing aid and conventional audiometric equipment. This is because the calibration, testing procedure, and hearing aid fitting are all under computer control. The digital hearing aid dispensed in this manner can be reprogrammed at any time. Thus, if the hearing aid user is not satisfied with the hearing aid, changes to it can be made without the need to switch to a different model. Similarly, if there is a change in the hearing of the user, the hearing aid characteristics can be adjusted to the user's current needs.

Because the digital hearing aid will contain very few analog parts, and because the characteristics of the hearing aid are stored in the software, its performance should remain stable over time. This will result in fewer problems with the hearing aid and greater user satisfaction.

The ability to "tailor fit" the hearing aid to the user makes the specification of the parameters of the hearing aid more important than ever. At present, the traditional comparative hearing aid evaluation procedure introduced by Carhart (2) is still used by many audiologists (11). However, even audiologists who use prescriptive procedures are limited to commercially available hearing aids. The difficulty of finding a commercial hearing aid that will exactly

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match the gain and saturation sound pressure level (SSPL) specified by a particular prescriptive fitting procedure was demonstrated in a recent study by Punch (8). It usually means that the hearing aid dispensed to the user will probably deviate somewhat from the specifications of the prescriptive procedure. This can be problematic because research has shown that differences in frequency response as small as 3 dB can affect the intelligibility of the speech signal (1).

At present, in order to get the desired parameters, the audiologist can calculate the requisite electroacoustic characteristics according to a specific prescriptive procedure. Alternatively, he can use a computer program to do these calculations (the software for several different prescriptive procedures is commercially available). He then may choose the hearing aid he feels most closely matches the desired parameters, or he may search a data base of available instruments to find the best match. Once the best match is identified, the audiologist can adjust the tone controls and choose an appropriate earmold to match the prescription as closely as possible.

A digital fitting system lends itself to the use of prescriptive hearing aid fitting procedures. Many prescriptive procedures have been developed for specifying the frequency response and the maximum power output of analog hearing aids. These procedures can also be used with digital aids. (For example, in the system described by Engebretson et al., a prescriptive procedure developed at the Central Institute for the Deaf was implemented). However, little attention has been given to prescriptive techniques used with compression hearing aids or other hearing aids with special forms of processing. Adaptive test procedures seem to provide a powerful method for specification of the parameters of these more complex systems (6).

As with any new clinical equipment, the audiologist will need to learn how the computer fitting system works and then learn how to use it. However, the audiologist will not need to become an expert computer programmer in order to use digital hearing aids and the associated computerized fitting system. He will only need to know how to use a computer and understand how digital hearing aids work. It is expected that the software for the measurements necessary to implement various prescriptive procedures and the algorithms for various prescriptive procedures will be commercially available. Courses in computer applications for audiologists and in digital signal processing are already part of the audiology curriculum at some universities. Practicing audiologists will need to expand their knowledge in these areas.

Although the actual fitting procedure will be simplified and made more efficient through the availability of digital systems, the audiologist will need to clearly understand the nature of a client's hearing loss in order to fit the digital hearing aid. Digital signal processing will make it possible to design hearing aids that differ significantly from currently available hearing aids. Noise reduction hearing aids, speech feature enhancement hearing aids, and hearing aids that process the signal to compensate for poor frequency resolution (spectral enhancement or spectral simplification) or abnormal temporal resolution of a particular ear are some of the processing capabilities that may be available on a wearable digital hearing aid in the future.

In order to fit the new aids it is necessary to

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determine which form of processing will benefit a particular client.

At present, few critieria have been developed to indicate when options such as a directional microphone, noise reduction circuitry, or compression amplification should be used. In some cases, information obtained from the client's history is a determining factor. For instance, a hearing aid with a directional microphone or with a noise reduction circuit may be prescribed for the hearing aid user who complains of an inability to function in noisy situations. But, there is no way to determine which of these options will be of greater benefit without allowing the person to try each of the options in the environments that cause the most difficulty. In other cases, a diagnostic test may be used to determine if a certain type of hearing aid may be beneficial. For example, recruitment or a narrow dynamic range may be taken as an indication that compression amplification should be prescribed. Diagnostic techniques need to be developed that will identify the form of processing most appropriate for a particular individual. As an example, the simultaneous masking paradigm described by Stelmachowicz et al. (14) may be useful in determining candidacy for compression amplification, as well as for determining the parameters of the compression amplification system.

Research has shown that, while some individuals may benefit from a particular form of signal processing, others do not. Specialized forms of compression improve speech recognition scores of some listeners with sensorineural hearing loss, but not of others (5,7). Similarly, noise reduction processing may be beneficial for certain listeners, but not for others (12,13). The information necessary to determine which listeners will benefit from a particular form of processing will become crucial as the number of different options increases.

Audiologists will need to become familiar with recent psychoacoustic and speech perception research in order to develop the clinical tests essential to the successful use of digital hearing aid systems. For example, in order to prescribe a hearing aid for spectral enhancement, the frequency resolution of the ear being fitted must be measured and the parameters of the processing system must be specified based on these measurements. Similarly, to compensate for abnormal temporal resolution, a clinical test of temporal resolution must be developed, as well as a prescriptive procedure that would use the information from that test. Clinical tests that use synthetic speech stimuli would allow the manipulation of certain cues in the speech signal. These tests could provide the information necessary to determine how processing might enhance the intelligibility of a speech signal for a particular individual.

The availability of digital hearing aids that process the signal in different ways will also necessitate that more attention be given to the aural rehabilitation process after fitting the hearing aid. When special types of processing are incorporated into a hearing aid, it may be necessary to train the hearing-impaired listener to make use of the processed signal (7,10). Revoile et al. (9) have described procedures for training listeners to discriminate and identify speech that had been processed to enhance specific features. These discrimination and identification exercises, with feedback given to the listener, are easily administered if a computer is used to automate the training task. Such procedures should also be helpful with other processing schemes.

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CONCLUSION

The computer already plays an important role in audiology and its importance is expected to increase in the future. The computer has the potential of dramatically improving amplification systems for those with hearing impairment. The availability of digital hearing aids can be expected to stimulate significant changes in the way hearing aids are prescribed and dispensed. It remains for the audiologist to develop the diagnostic techniques, the prescriptive methods, and the rehabilitation strategies necessary to make the technology work successfully for individual hearing aid users.

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