The APPLICATION of SIGNAL PROCESSING CONCEPTS to HEARING AIDS

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Editors

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HEAR Foundation (Hearing Education Audiological Research), a nonprofit public corporation, is dedicated to the correction of auditory impairment through research, education, and the development of equipment for training, testing, teaching, and sound protection for the hearing-handicapped.

The proceedings of the Symposium on which this volume is based are intended for all members of the hearing health care system concerned with improvement of current hearing aid selection procedures. The latest concepts and technological advances are presented, in the hope of to stimulate further endeavor in the field of hearing aid research and development.

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INTRODUCTION

On September 10th and 11th, 1977, the HEAR Foundation, in conjunction with the New Jersey College of Medicine and Dentistry and Newark Eye and Ear Infirmary, sponsored the First Symposium on the Application of Signal Processing Concepts to Hearing Aids. Many new concepts and developments in the area of sensorineural hearing loss and hearing aids have emerged from this symposium. Although this book is based on some of the symposium proceedings, its main intent is to provide useful information to members of the hearing health care team concerned with improvement of rehabilitation procedures in the area of sensorineural deafness. It sets forth important observations while emphasizing practical new ideas that are available to provide compensatory signal processing for persons with sensorineural hearing loss.

During the past decade I have often marveled at the miracles of modern day science. Astronauts communicating to us from the moon, microcomputors that generate synthetic speech and many more of the fantastic feats of modern day electrotechnology constantly occur.

Despite these rather awesome advances in American Technology, today's hearing aids are still frustrating implements of poor fidelity. It is no wonder that out of 15 million hearing impaired Americans, only approximately 2.5 million have purchased a hearing aid. Out of these 2.5 million hearing aid users, I would surmise that probably many of these people are part-time users and/or do not wear their aids at all. This diminutive use of hearing aids is a reflection on all of us—from the industry to members of the hearing health care system. It deprives the hearing impaired of better hearing and it unmistakably deducts from our sense of accomplishment.

Audiology encompasses a broad range of related sciences. An analysis of the audiological problems related to hearing rehabilitation and hearing aids reveals the need for communication among the fields of pyschoacoustics, audioengineering and speech communication research. Inter-relationships between these fields is difficult and generates disagreements between experts partly because of the complexity of knowledge one needs to acquire within each area. Teamwork among these fields consisting of educational seminars and group research efforts can facilitate progress and improve upon the current weaknesses of the hearing health care team. For the above reason, this book will draw together the experiences of various experts in such a way that their contributions may be useful and applicable to the clinical audiologist, the otologist and the hearing aid dealer. The following chapters will review current knowledge and technological advances and suggest badly needed improvements in the area of hearing rehabilitation and hearing aids.

The task of audiology in the detection and rehabilitation of sensorineural hearing loss must be further broadened and refined to predict finer details of pathology. When assessing the status of the sensorineural system, we must consider that some forms of sensorineural hearing loss are medically treatable and can be stabilized or reversed. We must develop a new attitude toward sensorineural hearing loss and combine our efforts with the otologist in reversing and arresting further hearing loss. We have two courses open to us: one is to attempt to arrest or reverse the process of hearing loss; and the other is to provide compensatory signal processing for the hearing loss. It should be emphasized that satisfactory achievement of the above tasks warrants the identification and quantification of aberrant auditory phenomena associated with various forms of sensorineural hearing loss. Several portions of this book reflect the need for extreme sophistication in the area of sensorineural hearing loss and a call is made for an insightful and diversified research approach in order to combat the intractability of sensorineural deafness.

Audiology is an evolving science struggling to meet the many technological advances that it is offered by its related sciences, namely, psychoacoustics and engineering. The expertise in modern electrotechnology for processing signals in much more sophisticated ways is available. Audiology must utilize these signal processing schemes and learn how it can meet the needs and capabilities of the hearing impaired. Application of this sophisticated technology can increase our present capabilities in the hearing aid selection procedure and, hence, improve listener performance for the hearing impaired.

A review of audiological research on the amplification needs of the hearing impaired has been limited and scanty. Many of the unanswered questions regarding amplification still remain and there are more unresolved clinical uncertainties and controversies now than there were a decade ago. The limitations of audiology as it relates to hearing aid selection are evident. The competent clinical audiologist who is concerned with the needs of his patients cannot rely solely on the clinical researcher to present answers on how to apply amplification to the many complexities of hearing losses generated by the clinical population. His decision must be based on clinical experience and knowledge of the proper instrumentation and signal processing schemes offered by today's technology. Carhart stated in 1975:

> Practicing the contemporary art of hearing aid selection involves taking shortcuts and making intuitive decisions which preclude obtaining the full array of information needed to generate the science of hearing aid selection. Clinical Audiology must generate new investigative methods capable of generating such a science and must employ these methods vigorously.*

Such a turn of events will result only if the interest and efforts of many researchers and clinical audiologists are solicited and combined into an educational forum. Future symposia on signal processing are planned to enlist the endeavors of clinical audiologists and researchers. The time has come for a reorganization of our current thinking and a change in philosophy which will make clinical audiology a viable force in the area of hearing rehabilitation and hearing aids.

Our efforts need to be directed towards: (1) increasing continuing education which, in effect, would promote a higher level of clinical competence; and, (2) decreasing the gap which exists today between practical application and theoretical research. Workshops and short courses should be organized if the current state of the art is to be advanced. This, in effect, would stimulate the hearing aid industry to implement and develop the higher level of sophistication needed in the area of hearing aids. If research and development costs are too high for this type of change, then funds should be solicited to cover developmental costs.

It is a known fact that government and foundation support for research and development attendant to hearing aid advancement is limited. Furthermore, the hearing aid industry, being too small in relation to major industry, is reluctant to change its ways. However, they are simply too far behind today's technology to sit still. If the industry does not change its approach soon, it should, and I suspect will, be bypassed. Hearing loss is a major national health problem that is currently being compounded by consumer exposure to the current turmoil between hearing health care professionals. We will not solve our hearing aid problems by court battles and in-fighting within the profession.

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*Carhart R: Introduction, in Pollack M (ed), Amplification for the Hearing Impaired, New York, Grune & Stratton, 1976

The answer lies in the development of better quality hearing health care and a realization of our goal—the rightful need of the hearing impaired to hear better.

It is hoped that the following chapters will stimulate the clinical audiologists, otologists and hearing aid dealers to improve upon the current hearing health care system, and that the aforementioned people make every effort to enlist one another's help in soliciting and maintaining the patient's participation during the hearing rehabilitation process. Our efforts should be directed to assure the availability and delivery of quality care for the hearing impaired. The attainment of this goal is predicated upon the development and use of sophisticated, scientific instrumentation from which will emerge new knowledge and technology.

Finally, I would like to extend my sincere thanks to the contributors to this book for their efforts and prompt response to requests for manuscripts. I would also like to thank my co-editor, Stephen Freifeld, M.D., for his dedication to the purpose of this book, and Linda Ripish, who has been involved in all aspects of preparation of the manuscript.

PAUL YANICK, JR., M.A.

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Chapter 1

DISTORTION IN THE COCHLEAR DAMAGED EAR

Paul Yanick, Jr., M.A.

Introduction

Just as any electroacoustic amplification system can generate distortions which decrease the clarity of the speech message it transmits, distortions produced by the ear can modify the acoustic clarity to such an extent as to reduce speech intelligibility. The ability of the cochlea to receive acoustic information and code it into appropriate neural excitation patterns determines the intelligibility of complex signals such as speech.

The fact that there remains inconsistencies between audiometric findings and speech discrimination ability for subjects with cochlear losses suggests a need for a careful exploration of distortion generated by the cochlear damage ear. Improved understanding of the nature of these auditory distortions will make it possible to implement compensatory signal processing systems and possibly reduce or circumvent the handicapping effect of impaired hearing.

The transformation of acoustic information into neural excitation patterns in the cochlea is achieved in several steps, each of which is bound and dependent on certain structural characteristics. For instance, traveling wave transformation relies on the mechanical properties of the cochlea and the mechano-electrical transduction that occurs in the hair cells by means of their interconnection to the tectorial membrane and on the basis of the cochlear resting potential.

There are many pathological conditions that exist in the cochlea. Each pathology can damage or alter the physical properties of mass, stiffness or elasticity in its own particular way. In addition, the degeneration of hair cells can occur in a variety of different ways along the basilar membrane.

Distortion of the inner ear is probably one of the least understood aspects of the functional operations of the ear. According to Dallos (1), "The mechanism of distortion generation is a subject of considerable disagreement. The difficulties attendent on treating and understanding non-linear behavior are some of the prime causes for inadequate and often confused treatment of such phenomena."

It is difficult to predict and make generalizations on how the ear actually distorts speech since measurement procedures require a reliance on subjective data from psychoacoustic tests. Consequently, knowing of the presence of one type of distortion is not enough. We need to know if it is combined by other distortions, so that we can look at each separately and make an estimate as to its severity or lack of severity. Once we have attempted to analyze the problem of each specific distortion generated, we may then attempt to process speech so as to ungarble it for the cochlear damaged ear. In evaluating these factors, for instance, we may be certain that the phenomenon occurred and we can then work appropriately to reduce the devastating effects of some of these distortions.

DISTORTION AS A RESULT OF THE SENSITIVITY LOSS

The most obvious form of distortion in the cochlear damaged ear results from the increased auditory thresholds. The hearing threshold loss itself deprives the ear of meaningful speech cues that occur below threshold. This kind of distortion is frequency dependent and commonly reduces sensitivity for the higher frequency components of speech. The ear simply cannot reproduce all frequencies with the same relative amplitude as they are produced in the normal ear. The weaker speech sounds perceived near threshold are too faint to contribute to speech intelligibility, especially when they are embedded in noise.

Table 1
Consonant Discrimination and Slope of Loss

Slope at 1k	% Consonant Discrimination					
	40 dB	50 dB	60 dB	70 dB	80 dB	90 dB
15 dB/octave	65	78	90	90	90	90
25 dB/octave	30	45	60	70	65	65
30 dB/octave	14	20	30	47	50	45

Table 1 is a summary of some recent data I collected on three groups of four subjects. All of these subjects had normal hearing at frequencies below 1000 Hz. Each group had different audiometric slopes at 1000 Hz of 15, 25, and 30 dB/octave. Consonant discrimination was assessed at intensity levels of 40, 50, 60, 70, 80, and 90 dB with the California Consonant Test (2). As would be expected, the discrimination scores improved considerably as the input intensity was increased. As the filtering effect of the hearing loss increased the consonant discrimination ability decreased proportionately.

If we present speech to the normal ear and distort the frequency relationships by simulating the filtering effect of various high frequency sloping sensorineural hearing loss cases we could observe the reduction of discrimination due to the loss of the high frequency components of speech. This reduction in discrimination loss however, may not match the actual discriminative function of the pathological ear since we have not attempted to analyze the possible contribution of other distortions to the degradation of speech.

The speech wave has a variety of many different cues that are available to enhance a given speech element or phoneme. The filtering effect of the hearing threshold loss reduces the amount of these cues available and in effect, reduces the degree of redundancy of the speech wave. This redundancy is further reduced when other distortions are generated by the ear. Other factors to consider are the masking effects of acoustical interference and background noise, low fidelity hearing aid circuitry and speaker articulation.

PITCH DISTORTION

The pitch discriminative function of the pathological ear has received limited attention by researchers and has been ignored by the clinical population. Available evidence (3) regarding the etiology of the aberrations in pitch perception generated in the cochlea suggests that a reduction in the hair cell population decreases the ability of the cochlea to detect slight differences in frequency between two separate signals. The DL or difference limens for pitch provides an index of auditory acuity which cannot be ignored when assessing the auditory capabilities of the cochlear damaged ear.

Butler and Albrite (4), compared the pitch discrimination ability in subjects with sensorineural hearing loss and conductive hearing loss. They found higher DL in the sensorineural group especially where the hearing loss was more severe at frequencies 3000 and 4000 Hz.

Parker, Decker and Gardner (5), measured DL in normal subjects and subjects with cochlear hydrops and demonstrated that DL in the pathological ear is inversely related to the stimulus intensity. They present monaural pitch discrimination as an aberration in pitch that is somewhat masked by the "presence of recruitment and changes in the timber of acoustic stimuli." The pathological subjects in this study had abnormal pressure changes with a tendency for low tone sensorineural hearing loss. Increasing the intensity in these subjects, as also demonstrated by Davis (6) and Schubert (7) in noise damaged ears, decreased the pitch aberrations of their subjects. On the other hand, Harris, Haines and Myers (8), found that not all patients that have intensity distortion or recruitment have pitch distortion.

The precise measurements for the exact determination of DL for pitch would make it time consuming and