

SECOND EDITION

ACOUSTICAL
FACTORS
— AFFECTING —
HEARING AID
PERFORMANCE



GERALD A. STUDEBAKER
IRVING HOCHBERG

ACOUSTICAL FACTORS AFFECTING HEARING AID PERFORMANCE

SECOND EDITION

Edited by

GERALD A. STUDEBAKER, Ph.D.

*Distinguished Professor
Department of Audiology and Speech Pathology
Memphis State University*

IRVING HOCHBERG, Ph.D.

*Professor and Executive Officer
Doctoral Program in Speech and Hearing Sciences
Graduate School, City University of New York*

ALLYN AND BACON

Boston London Sydney Toronto



ISBN 0-205-13778-4
H37781



Copyright © 1993, 1980 by Allyn and Bacon
A Division of Simon & Schuster, Inc.
160 Gould Street
Needham Heights, MA 02194

All rights reserved. No part of the material protected by this copyright notice may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying, recording, or by any information storage and retrieval system without written permission from the copyright owner.

Library of Congress Cataloging-in-Publication Data

Conference on Acoustical Factors Affecting Hearing Aid Measurement and Performance (1978 : New York, N.Y.)
Acoustical factors affecting hearing aid performance / edited by Gerald A. Studebaker and Irving Hochberg. — 2nd ed.
p. cm.
Includes bibliographical references and indexes.
ISBN 0-205-13778-4
1. Hearing aids—Design and construction. 2. Hearing aids—Fitting.
3. Speech perception. I. Studebaker, Gerald A. II. Hochberg, Irving.
III. Title.
RF300.C6 1978b
617.8'9—dc20 92-20408
CIP

Printed in the United States of America

10 9 8 7 6 5 4 3 2 96 95 94 93 92

BRIEF CONTENTS

Detailed Contents	ix
Preface	xix
Contributing Authors	xxi

PART ONE THE ENVIRONMENT 1

CHAPTER 1	Normal Listening in Typical Rooms: The Physical and Psychophysical Correlates of Reverberation	3
	<i>David A. Berkley and Jont B. Allen</i>	
CHAPTER 2	Communication in Noisy and Reverberant Environments	15
	<i>Anna K. Nábělek</i>	

PART TWO THE HEARING AID 29

CHAPTER 3	Transducers and Acoustic Couplings: The Hearing Aid Problem That Is (Mostly) Solved	31
	<i>Mead C. Killion</i>	
CHAPTER 4	Measuring the Performance of Modern Hearing Aids	51
	<i>Edward Cudahy and James Kates</i>	
CHAPTER 5	CORFIG and GIFROC: Real Ear to Coupler and Back	65
	<i>Mead C. Killion and Lawrence Revit</i>	

PART THREE HEARING AID SELECTION 87

CHAPTER 6	Acoustical Methods for Selecting Hearing Aids	89
	<i>David B. Hawkins</i>	
CHAPTER 7	The Application of Adaptive Test Strategies to Hearing Aid Selection	103
	<i>Arlene C. Neuman and Harry Levitt</i>	

- CHAPTER 8 Implications of the National Acoustic Laboratories' (NAL) Research for Hearing Aid Gain and Frequency Response Selection Strategies 119
Denis Byrne
- CHAPTER 9 Effects of Frequency Response, Bandwidth, and Overall Gain of Linear Amplification Systems on Performance of Adults with Sensorineural Hearing Loss 133
Margaret W. Skinner
- CHAPTER 10 Amplification for the Profoundly Hearing Impaired 167
Mark Ross

PART FOUR
THEORETICAL ISSUES 183

- CHAPTER 11 Frequency-Importance Functions for Speech Recognition 185
Gerald A. Studebaker and Robert L. Sherbecoe
- CHAPTER 12 Some Temporal Factors Affecting Speech Recognition 205
Larry E. Humes
- CHAPTER 13 Problems in the Prediction of Speech Recognition Performance of Normal-Hearing and Hearing-Impaired Individuals 221
Chaslav V. Pavlovic
- CHAPTER 14 Factors Affecting Performance on Psychoacoustic and Speech-Recognition Tasks in the Presence of Hearing Loss 235
Judy R. Dubno and Donald D. Dirks
- CHAPTER 15 Binaural Advantages and Directional Effects in Speech Intelligibility 255
P.M. Zurek
- CHAPTER 16 Speech Perception, Sensorineural Hearing Loss, and Hearing Aids 277
Arthur Boothroyd
- CHAPTER 17 Subjective Correlates of the Acoustical Characteristics of Sound-Reproducing Systems 301
Alf Gabrielsson and Björn Hagerman

PART FIVE
SIGNAL PROCESSING 315

- CHAPTER 18 Digital Hearing Aids 317
Harry Levitt
- CHAPTER 19 Noise Reduction in Hearing Aids 337
Mark Weiss and Arlene C. Neuman
- CHAPTER 20 Single-Microphone Noise Reduction Systems for Hearing
Aids: a Review and an Evaluation 353
Harvey Dillon and Roger Lovegrove
- CHAPTER 21 Some Acoustic Enhancements of Speech and Their Effect on
Consonant Identification by the Hearing Impaired 373
Sally G. Revoile and Lisa D. Holden-Pitt
- Author Index 387
- Subject Index 389

DETAILED CONTENTS

Preface xix

Contributing Authors xxi

PART ONE THE ENVIRONMENT 1

CHAPTER 1	Normal Listening in Typical Rooms: The Physical and Psychophysical Correlates of Reverberation	3
	<i>David A. Berkley and Jont B. Allen</i>	
	Physical Basis of Reverberation	3
	<i>Definitions</i>	3
	<i>Intelligibility Versus Preference</i>	3
	<i>Ideal Rooms</i>	4
	<i>Transfer Function</i>	4
	Perception of Reverberation	5
	<i>Perception for One Reflection</i>	5
	<i>Perception in Real Rooms</i>	6
	<i>The Allen-McDermott Experiment</i>	7
	<i>Experimental Results</i>	8
	Summary	12
	<i>Appendix to Chapter 1</i>	12
	Room Simulation	12
	<i>Basic Physical Principles</i>	12
	<i>Computer Implementation</i>	12
	<i>The Spectral Deviation</i>	13
	References	14
CHAPTER 2	Communication in Noisy and Reverberant Environments	15
	<i>Anna K. Nábelek</i>	
	Effect of Noise on Speech Perception	15
	<i>Speech Tests</i>	15
	<i>Speech Intelligibility for Various Talkers</i>	15
	<i>SPL for Optimal Speech Perception</i>	16
	<i>Speech Perception for Various S/N</i>	16
	<i>Acoustic Cues Masked by Noise</i>	16
	Effect of Reverberation on Speech Perception	17
	<i>Room Reflections</i>	17

<i>Reverberation Time</i>	17
<i>Overlap- and Self-Masking</i>	18
<i>Weight of Acoustic Cues in Nonreverberant and Reverberant Fields</i>	18
Speech Perception in Noise and Reverberation for Hearing-Impaired Listeners	18
<i>Comparison with Data for Normal-Hearing Listeners</i>	18
<i>Perception of Consonants in Noise and in Reverberation</i>	19
<i>Perception of Vowels in Noise and in Reverberation</i>	20
<i>Individual Susceptibility to Noise and to Reverberation</i>	21
<i>Effect of Distance from the Source</i>	22
<i>Differences Between Binaural and Monaural Listening</i>	23
<i>Effect of Age</i>	23
<i>Non-Native Listeners</i>	25
Summary	26
References	26

PART TWO THE HEARING AID 29

CHAPTER 3	Transducers and Acoustic Couplings: The Hearing Aid Problem That Is (Mostly) Solved	31
	<i>Mead C. Killion</i>	
	Transducers and Couplings	31
	<i>Transducer Miniaturization</i>	31
	<i>Transducer Types</i>	32
	<i>Performance Versus Size</i>	33
	The Traditional Problem Areas	38
	<i>Bandwidth</i>	38
	<i>Frequency Response Shaping</i>	39
	<i>Receiver-Plus-Earmold Response</i>	41
	<i>Amplifier Source Impedance</i>	41
	<i>Noise</i>	45
	<i>Distortion</i>	46
	Summary	48
	References	49
CHAPTER 4	Measuring the Performance of Modern Hearing Aids	51
	<i>Edward Cudahy and James Kates</i>	
	Electroacoustic Measurement Issues	51
	<i>Linear Processing</i>	51
	<i>Automatic Gain Control</i>	52
	<i>Noise Suppression (Automatic Signal Processing)</i>	52
	<i>Multi-Channel Processing</i>	53
	<i>Digital Signal Processing</i>	53

Hearing Aid Measurement Procedures 54
Frequency Response 54
Input/Output Characteristic 55
Distortion Measurement 55
Compression Characteristics 55
Type of Processing 55
 Computerized Measurement System 56
 Preliminary Results 56
 The Measurement of Distortion 58
 A Distortion Index 59
 Summary 62
 References 63

CHAPTER 5 CORFIG and GIFROC: Real Ear to Coupler and Back 65
Mead C. Killion and Lawrence J. Revit
 Definitions and Relationships 65
 2-cc Coupler Gain and Zwislocki Coupler Gain 65
 Real-Ear-to-Coupler Level Difference (RECD) 65
 Functional Gain and Insertion Gain 66
 The REAR, REUR, REIR, REIG, REOR Acronyms 68
 CORFIG: The Insertion Response to Coupler Response Transformation 69
 Ordering the 2-cc Coupler Response 70
 Transforming Target Insertion Response to Target 2-cc Coupler Response 70
 Individual Differences 7
 Modifying the Target 2-cc Coupler Response 74
 GIFROC: The Coupler Response to Insertion Response Transformation 77
 Average-Ear CORFIG and GIFROC Data 78
 Diffuse-Sound-Field Data 78
 0-, 45-, and 90-Degree Sound-Field Data 79
 Minimizing Measurement Variability 81
 The Unanswered Questions 84
 References 84

PART THREE
HEARING AID SELECTION 87

CHAPTER 6 Acoustical Methods for Selecting Hearing Aids 89
David B. Hawkins
 Functional Gain 89
 Definition and Uses of Functional Gain 89
 Procedural Issues in Functional Gain 90
 Research Needs in Functional Gain 91

	Ear Canal Probe Tube Microphone Measurements (PTM)	91
	<i>History of PTM</i>	91
	<i>Definitions of Types of PTM</i>	92
	<i>Uses of PTM</i>	92
	<i>Procedural Issues in PTM</i>	94
	<i>Research Needs in PTM</i>	99
	Conclusion	100
	References	100
CHAPTER 7	The Application of Adaptive Test Strategies to Hearing Aid Selection	103
	<i>Arlene C. Neuman and Harry Levitt</i>	
	Adaptive Strategies	104
	<i>Convergence Strategies</i>	105
	<i>Convergence Strategies in Hearing Aid Research</i>	106
	<i>Tournament Strategies</i>	113
	Clinical Application of Adaptive Testing	115
	References	116
CHAPTER 8	Implications of the National Acoustic Laboratories' (NAL) Research for Hearing Aid Gain and Frequency Response Selection Strategies	119
	<i>Denis Byrne</i>	
	NAL Hearing Aid Selection Research and Procedures	119
	Fundamental Issues	120
	<i>Justification for Frequency Response Selection</i>	120
	<i>Significance of Differences in Frequency Response</i>	121
	<i>Amounts of Signal Received</i>	123
	<i>Relationship of Audiometric Measures to Gain and Frequency Response Requirements</i>	124
	Prescription Rules and Principles	125
	<i>Gain Prescription Rules</i>	125
	<i>Frequency Response Prescription Rules</i>	128
	<i>Need to Vary Gain and Frequency Response at Different Times</i>	129
	Conclusions	130
	References	130
CHAPTER 9	Effects of Frequency Response, Bandwidth, and Overall Gain of Linear Amplification Systems on Performance of Adults with Sensorineural Hearing Loss	133
	<i>Margaret W. Skinner</i>	
	Analysis of Research Results	135
	<i>Relation of Amplified Speech to Residual Hearing</i>	135

	<i>Choice of Most Intelligible Level for Long-Term Listening Comfort (MIL) as a Function of Frequency Response: Uniform versus High-Frequency Emphasis Responses</i>	141
	<i>How Much High-Frequency Emphasis is Appropriate?</i>	143
	<i>Frequency Responses for Binaural Amplification</i>	149
	<i>Effective Bandwidth</i>	149
	<i>Overall Gain</i>	152
	Evaluation of Clinical Prescriptive Procedures	153
	<i>Validation of the Revised NAL Procedure</i>	153
	<i>High-Frequency Emphasis Prescribed by the POGO and Berger Procedures</i>	154
	<i>Real-Ear Gain Prescribed by Procedures Based on Judgments of Supra-Threshold Loudness</i>	156
	Implications for Clinical Fitting of Hearing Aids and Future Research	160
	<i>Optimize Coupling of Hearing Aid to the Ear</i>	160
	<i>Focus on the Individual</i>	160
	<i>Study Groups with the Same Audiometric Configuration</i>	161
	<i>Select Speech and Noise Stimuli to Differentiate Between Amplification Parameters</i>	161
	<i>Select Relevant Sets of Frequency-Gain Characteristics for Evaluation</i>	161
	<i>Evaluate Nonlinear Hearing Aids</i>	163
	References	163
CHAPTER 10	Amplification for the Profoundly Hearing Impaired	167
	<i>Mark Ross</i>	
	Residual Auditory Capacities	167
	Prescription Formulas	169
	<i>Rationale</i>	169
	<i>Evaluating Current Prescription Procedures</i>	169
	Aided Audibility	173
	A Clinical Investigation of Speech Perception in Profoundly Hearing-Impaired Children	178
	Summary	179
	References	180

PART FOUR

THEORETICAL ISSUES 183

CHAPTER 11	Frequency-Importance Functions for Speech Recognition	185
	<i>Gerald A. Studebaker and Robert L. Sherbecoe</i>	
	Articulation Theory	185

	Past and Present Importance Functions	186
	One Importance Function or Many?	187
	Factors Affecting Frequency-Importance Functions	189
	<i>Stimulus Variables</i>	189
	<i>Measurement Variables</i>	192
	How Important Are Importance Functions	194
	<i>Unaided Hearing Loss</i>	195
	<i>Aided Hearing Loss</i>	195
	Conclusion	200
	<i>Appendix to Chapter 11</i>	201
	References	201
CHAPTER 12	Some Temporal Factors Affecting Speech Recognition	205
	<i>Larry E. Humes</i>	
	Speech Transmission Index (STI)	205
	<i>The Modulation Transfer Function (MTF)</i>	205
	<i>Frequency Weighting</i>	210
	<i>The modified Speech Transmission Index (mSTI)</i>	212
	Applications to Hearing-Impaired Listeners	213
	<i>The Audibility Factor</i>	213
	<i>Factors Other Than Audibility</i>	217
	References	218
CHAPTER 13	Problems in the Prediction of Speech Recognition Performance of Normal-Hearing and Hearing-Impaired Individuals	221
	<i>Chaslav V. Pavlovic</i>	
	A Historical Note	221
	Basic Formulae	222
	Importance Function	223
	Weighting Factor	225
	<i>Speech Dynamic Range</i>	225
	<i>Effective Level of External Noise</i>	228
	<i>Hearing Threshold</i>	229
	<i>Nonlinear Systems and Distortions in the Time Domain</i>	229
	<i>High-Level Speech</i>	229
	Proficiency Factor	229
	Transfer Function	230
	Issues Related to Hearing Loss	230
	<i>Issues Relevant to Hearing Aid Selection</i>	232
	<i>Issues Relevant to Studying Suprathreshold Speech Processing</i>	232
	Conclusions	232
	References	233

CHAPTER 14	Factors Affecting Performance on Psychoacoustic and Speech-Recognition Tasks in the Presence of Hearing Loss	235
	<i>Judy R. Dubno and Donald D. Dirks</i>	
	Comparing Performance of Normal-Hearing and Hearing-Impaired Listeners	236
	<i>Frequency and Temporal Resolution</i>	236
	<i>Speech Recognition</i>	237
	<i>Summary</i>	239
	Experiment I: Associations Among Frequency Resolution and Stop-Consonant Recognition for Hearing-Impaired Listeners	240
	<i>Implications of the Results</i>	242
	Experiment II: Frequency Resolution for Masked Normal-Hearing Listeners	243
	<i>Auditory-Filter Characteristics</i>	243
	<i>Critical Ratios</i>	244
	<i>Forward-Masked Psychophysical Tuning Curves</i>	245
	<i>Narrowband-Noise Masking Patterns</i>	247
	<i>Implications of the Results</i>	250
	General Discussion	250
	Conclusions	251
	References	251
CHAPTER 15	Binaural Advantages and Directional Effects in Speech Intelligibility	255
	<i>P.M. Zurek</i>	
	The Model	256
	<i>Monaural Listening</i>	258
	<i>Binaural Listening</i>	259
	Comparisons to Data	261
	<i>Directional Effects</i>	262
	<i>Binaural Advantages</i>	264
	<i>Analytic Studies</i>	266
	Further Predictions	269
	<i>Filtering</i>	269
	<i>Head Movements</i>	271
	The Binaural Advantage	272
	Discussion	273
	References	275
CHAPTER 16	Speech Perception, Sensorineural Hearing Loss, and Hearing Aids	277
	<i>Arthur Boothroyd</i>	
	Speech Perception	277
	Communication by Spoken Language	277

Acoustic Speech Patterns	280
<i>Speech Intensity</i>	280
<i>Average Spectrum</i>	280
<i>Intensity and Frequency Ranges</i>	280
<i>Spectral and Temporal Detail</i>	281
Movement Patterns of Speech	283
<i>Sound Generation</i>	284
<i>Resonance</i>	284
<i>Phoneme System</i>	284
<i>Vowels</i>	285
<i>Consonants</i>	286
<i>Segmentation and Invariance</i>	286
The Normal Listener	286
<i>Phoneme Recognition Probability versus Intensity</i>	286
<i>Recognition Probability versus Frequency</i>	288
<i>Subphonemic Features versus Frequency</i>	288
<i>Spectral Patterns and Phoneme Identification</i>	289
<i>Visible Speech Patterns</i>	289
<i>Quantitative Methods</i>	290
<i>Effects of Context</i>	291
Effects of Sensorineural Hearing Loss	292
<i>Threshold</i>	292
<i>Reduced Dynamic Range</i>	292
<i>Time and Frequency Resolution</i>	292
<i>Perception of Speech Pattern Contrasts</i>	292
<i>Prelingual Deafness</i>	294
<i>Children</i>	294
Implications for Hearing Aids	294
<i>The Threshold Problem</i>	294
<i>The Dynamic Range Problem</i>	294
<i>The Spectral and Temporal Resolution Problem</i>	295
<i>Noise</i>	296
<i>Need for Predictability</i>	296
<i>Evaluation of Aided Speech Perception Performance</i>	296
Summary	297
References	298

CHAPTER 17	Subjective Correlates of the Acoustical Characteristics of Sound-Reproducing Systems	301
	<i>Alf Gabrielsson and Björn Hagerman</i>	
	Methods and Results	302
	<i>Identification of Perceptual Dimensions</i>	302
	<i>Measurement Scales for Perceptual Dimensions</i>	306
	<i>Perceptual Dimensions and Overall Quality</i>	309

<i>Relations to Physical Variables</i>	310
<i>Clinical Applications</i>	313
Concluding Remarks	313
References	314

PART FIVE
SIGNAL PROCESSING 315

CHAPTER 18	Digital Hearing Aids	317
	<i>Harry Levitt</i>	
	Early Experiments with Off-Line Simulation	317
	Digital Simulation of Hearing Aids Operating in Real Time	318
	Noise Reduction Using Digital Hearing Aids	321
	Signal Processing for Speech Enhancement	324
	<i>A Generalized Approach to Amplitude Compression</i>	324
	<i>LDL Compression</i>	326
	<i>Reduction of Reverberation</i>	328
	Other Applications of Digital Signal Processing	329
	<i>Feedback Reduction</i>	329
	<i>Hearing Instruments Combining Multiple Functions</i>	330
	Summary	332
	References	333
CHAPTER 19	Noise Reduction in Hearing Aids	337
	<i>Mark Weiss and Arlene C. Neuman</i>	
	Degradation of Speech Perception in Noisy Environments	338
	Fundamental Considerations in Noise Reduction	338
	Evaluation of Noise Reduction Methods	339
	Noise Reduction Methods	340
	<i>Directional Microphones</i>	340
	<i>Broadband Amplitude Compressors</i>	341
	<i>High-Pass Filters</i>	341
	<i>Multiple Bandpass Filters</i>	342
	<i>Digital Noise Reduction</i>	342
	Results of Evaluations on Commercial Devices	342
	Digital Methods of Noise Reduction	343
	<i>Single-Microphone Methods</i>	343
	<i>Multiple-Microphone Methods</i>	346
	Applicability of Advanced Signal Processing Techniques to Hearing Aids	349
	References	350

CHAPTER 20	Single-Microphone Noise Reduction Systems for Hearing Aids: A Review and an Evaluation	353
	<i>Harvey Dillon and Roger Lovegrove</i>	
	Reasons for Poor Speech Discrimination in Noise	353
	<i>Binaural Effects and Localization</i>	353
	<i>Temporal Resolution</i>	354
	<i>Reduced Dynamic Range</i>	354
	<i>Frequency Resolution</i>	354
	Methods for Reducing Background Noise	354
	<i>Remote Signal Pick-Up</i>	354
	<i>Directional Microphones</i>	355
	<i>Signal Processing</i>	355
	Review of Results with Wearable Aids	358
	Evaluation of Noise Reduction Aids at the National Acoustic Laboratories (NAL)	361
	<i>Procedure</i>	361
	<i>Field Trial Results</i>	364
	<i>Laboratory Intelligibility Results</i>	365
	<i>Conclusions of NAL Evaluation</i>	368
	Concluding Discussion	369
	References	370
CHAPTER 21	Some Acoustic Enhancements of Speech and Their Effect on Consonant Identification by the Hearing Impaired	373
	<i>Sally G. Revoile and Lisa D. Holden-Pitt</i>	
	Consonant Amplification	375
	Duration Alterations	376
	Spectral Alterations	377
	Summary	378
	An Experiment on Enhanced Cue Audibility	379
	<i>Method</i>	379
	<i>Results</i>	380
	References	385
Author Index		387
Subject Index		389

PREFACE

More than ten years have passed since the convocation of the original "Acoustical Factors Affecting Hearing Aid Performance" conference in New York City in 1978. Much of the information presented at that conference was new and not widely known. In order to help distribute this important information more widely, the first edition of this book was published in 1980. Since then, much of the then-new information has become common coin. It has been incorporated into many laboratory procedures and clinical and sales office fitting practices. In fact, the extent of that knowledge in some areas has been sufficient to prompt Killion to state in Chapter 3 of this edition that transducer and coupling issues are "(mostly) solved." Thus, it would seem that, at least in the case of purely acoustical matters, a very great deal of progress has been made and that two primary tasks remain: the refinement of quantitative values and the generation of research and clinical procedures that incorporate these findings into methods that are more reliable, valid, efficient, and easier to use. Many of the chapters in this volume reflect these developments.

With the fundamental acoustical issues under good control, researchers during the past ten years have been better able to investigate other issues. One of the most important was the inherently more difficult problem of determining what characteristics the acoustical signal at the ear should have in order to best meet the needs of the hearing-impaired person. As these pages will reveal, digital hearing aids, and the signal processing they make possible, have opened up new and potentially fruitful avenues of research and development in this area. Noise reduction, multi-channel aids, phonemic feature enhancement, adaptive filtering, and more precisely fitted gain curves have all been put forward as techniques with great promise. But, early investigations suggest that none of these techniques is going to provide the dramatic breakthrough that will quickly solve the problems of the hearing impaired. Nevertheless, it seems likely that digital hearing aids will, one day, be the dominant type of hearing aid for the reason that they do offer significant advantages. However, it now appears that the gains they will provide will be incremental rather than dramatic.

Digital hearing aids increase the need for theoretical structure and basic research, precisely because these hearing aids open up so many new possibilities that the "cut-and-try" procedures of the past are less defensible than ever. Increased complexity calls for the guidance of unifying theory. Theoretical structure suggests what information is needed in order to use or test the theory and provides a framework within which to interpret the results. At present there are only a very small number of theoretical constructs that are broad enough to encompass most of the matters relevant to hearing aid selection and performance. Those that do exist are similar in that they all have fundamental features in common with classical Articulation Theory. Interest in theories of this type has increased over the past ten years, spurred on by the landmark paper by Dugal,

Braida, and Durlach (1980), which appeared in the first edition of this book. As a reflection of that fact, five of the chapters included in this edition are either about articulation theory-like concepts or use those concepts to assist in the interpretation of their results. It seems probable to us that such theories will receive substantially increased attention in the immediate future.

As a final note, we want to thank those who helped us in the preparation of this book. Especially, we want to thank the authors who so unselfishly devoted their time and effort to this project. In addition, we want to thank April V. Powel for her dedicated service in helping to prepare the manuscripts for publication. Her exceptional efforts are greatly appreciated.

Gerald A. Studebaker
Irving Hochberg

REFERENCES

- Dugal, R.L., Braida, L.D., and Durlach, N.I. (1980). Implications of previous research for the selection of frequency-gain characteristics. In Studebaker, G.A. and Hochberg, I. (Eds.), *Acoustical Factors Affecting Hearing Aid Performance*. Baltimore: University Park Press.
- Killion, M.C. (1992). Transducers and acoustic couplings: The hearing aid problem that is (mostly) solved. In Studebaker, G.A. and Hochberg, I. (Eds.), *Acoustical Factors Affecting Hearing Aid Performance*, 2nd ed. Boston: Allyn and Bacon.

CONTRIBUTING AUTHORS

Jont B. Allen
Acoustics Research Department
AT & T Bell Laboratories
600 Mountain Avenue
Murray Hill, New Jersey 07974

David A. Berkley
Acoustics Research Department
AT & T Bell Laboratories
600 Mountain Avenue
Murray Hill, New Jersey 07974

Arthur Boothroyd
Ph.D. Program in Speech and Hearing
Sciences
City University of New York
Graduate School and University Center
33 West 42nd Street
New York, New York 10036

Denis Byrne
National Acoustic Laboratories
126 Greville Street
Chatswood, NSW 2067, Australia

Edward Cudahy
The Lexington Center
30th Avenue and 70th Street
Jackson Heights, New York 11370

Harvey Dillon
National Acoustic Laboratories
126 Greville Street
Chatswood, NSW 2067, Australia

Donald D. Dirks
Division of Head and Neck Surgery
School of Medicine
University of California, Los Angeles
Los Angeles, California 90034

Judy R. Dubno
Department of Otolaryngology and
Communicative Sciences
Medical University of South Carolina
171 Ashley Avenue
Charleston, South Carolina 29425

Alf Gabrielsson
Department of Technical Audiology
Karolinska Institute
S-100 44 Stockholm, Sweden

Björn Hagerman
Department of Technical Audiology
Karolinska Institute
S-100 44 Stockholm, Sweden

David B. Hawkins
Department of Communication Disorders
University of South Carolina
Columbia, South Carolina 29208

Lisa D. Holden-Pitt
Center of Auditory and Speech Sciences
Gallaudet University
800 Florida Avenue, N.E.
Washington, DC 20002

Larry E. Humes
Department of Speech and Hearing Sciences
Indiana University
Bloomington, Indiana 47405

James Kates
Ph.D. Program in Speech and Hearing
Sciences
City University of New York
Graduate School and University Center
33 West 42nd Street
New York, New York 10036

Mead C. Killion
Etymotic Research
61 Martin Lane
Elk Grove Village, Illinois 60007

Harry Levitt
Ph.D. Program in Speech and Hearing Sciences
City University of New York
Graduate School and University Center
33 West 42nd Street
New York, New York 10036

Roger Lovegrove
National Acoustic Laboratories
126 Greville Street
Chatswood, NSW 2067, Australia

Anna K. Nábělek
Department of Audiology and Speech
Pathology
University of Tennessee
580 Stadium Annex
Knoxville, Tennessee 37923

Arlene C. Neuman
Ph.D. Program in Speech and Hearing
Sciences
City University of New York
Graduate School and University Center
33 West 42nd Street
New York, New York 10036

Chaslav V. Pavlovic
Department of Speech Pathology and
Audiology
University of Iowa
Iowa City, Iowa 52242

Lawrence Revit
Frye Electronics, Inc.
P.O. Box 23391
Tigard, Oregon 97223

Sally G. Revoile
Center of Auditory and Speech Sciences
Gallaudet University
800 Florida Avenue, N.E.
Washington, DC 20002

Mark Ross
Ph.D. Program in Speech and Hearing
Sciences
City University of New York
Graduate School and University Center
33 West 42nd Street
New York, New York 10036

Robert L. Sherbecoe
Department of Audiology and Speech
Pathology
Memphis State University
807 Jefferson Avenue
Memphis, Tennessee 38105

Margaret W. Skinner
Department of Otolaryngology
Washington University School of Medicine
517 South Euclid Avenue
St. Louis, Missouri 63110

Gerald A. Studebaker
Department of Audiology and Speech
Pathology
Memphis State University
807 Jefferson Avenue
Memphis, Tennessee 38105

Mark Weiss
Ph.D. Program in Speech and Hearing
Sciences
City University of New York
Graduate School and University Center
33 West 42nd Street
New York, New York 10036

P.M. Zurek
Research Laboratory of Electronics
Room 36-736
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

PART ONE

THE ENVIRONMENT

