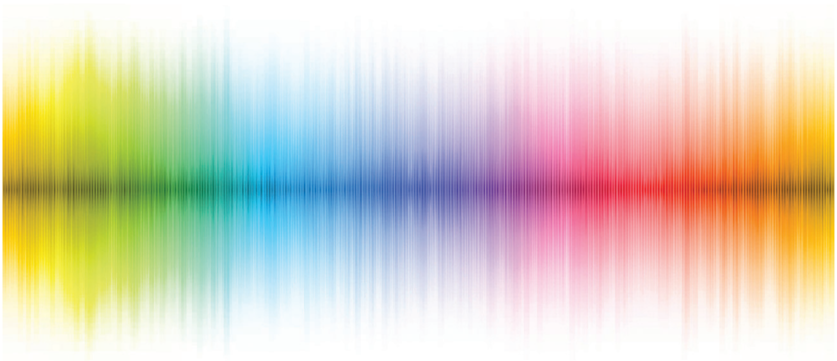
AUDIOLOGICAL RESEARCH OVER SIX DECADES

James Jerger, PhD



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Foreword

This book is an adventure. It tells the story of the evolution of diagnostic audiology through the voice of one of its greatest contributors, Dr. James Jerger. His story begins in the late 1950s during his formative years as a student of Raymond Carhart and other notables, continues through his prolific years at the Baylor College of Medicine, and ends with his final act at the University of Texas at Dallas. Jerger's lively narrative describes, in his wise and witty way, what he was thinking throughout six productive decades of game-changing audiological research. He provides us with a view, through case studies of his own work, of an unparalleled perspective, from the room where it happened.

I first met Dr. Jerger when he was lecturing at a symposium in Nashville in the late 1970s. I was a young master's degree student at Vanderbilt University. In those days, that was the clinical degree for entry into the audiology profession. I have this vague memory of that lecture, and it went something like this: He seemed to be presenting case after case after case, and I kept wondering, where are the data? In the classroom and from their treatment in the literature, of course, we were taught that a disorder is some sort of homogeneous entity and that test outcomes should be reflective of that. We were taught to wonder, *how do groups of people with the disorder perform on various diagnostic measures?* If they vary, then there must be something wrong with the test or, perhaps, with the disorder. It was not until I studied with Jerger that I began to understand.

In 1981, I joined the group at the Baylor College of Medicine as a PhD student under Dr. Jerger's tutelage. My first research assignment was in the lab of Dr. Makoto Igarashi and Dr. Glenn Thompson, where I was studying the effects of cortical control and the location of motoneurons of the stapedius reflex in squirrel monkeys. But at the end of every day, I would wander down to the clinic to join the clinical staff in their daily case staffings with Dr. Jerger. (I say daily, but during sailing season, we might be found sneaking away on Wednesday afternoons to Galveston Bay for an afternoon on Dr. Jerger's sailboat *Ixchel.*) It was at these staffings that I began to understand the tremendous value of peer review, the power of the test battery approach to clinical data collection, and the important lessons that we could learn from individual patients. After I graduated, I stayed on with the team at the Baylor College of Medicine and the Methodist Hospital of Houston for a number of years and never missed a case staffing. During my 11 years there, I came to know Jim Jerger as an excellent scientist with the strongest theoretical background, but one who had unmatched clinical credibility.

I tell you the story about case staffings because, as I was reading this book, I was struck by how often he uses case studies to help explain to you as a reader the point he is trying to make about the topic. In his Chapter 3 on auditory processing disorder (APD), he provides some historic background and some theoretical constructs, but then he teaches you about the nature of the disorder by showing you a well-studied and well-tested patient. Chapter 4 is all about a patient and Chapter 9 about twins. And he makes his most important teaching points by illustrating them in patient outcomes in his Chapter 5 on binaural hearing and in Chapter 6 on a very clever test of binaural listening. Finally, in Chapter 8, on auditory event-related potentials (AERPs), he says it best: "That is why we have focused so much of our work in AERPs on individual listeners, whether normal or abnormal: because as clinicians, we all want methods and techniques that we can use to investigate people, not groups of people." In these days of big data and meta-analysis, this is a refreshing reminder of the importance of the individual and what we can learn from the variability of individual clinical outcomes.

I left the Baylor College of Medicine in 1992. In those days, our only real mode of communication was the telephone, and back then, they had cords. So, communication was not as simple as today, and I remember how much I missed understanding Dr. Jerger's perspective on things. One thing I could count on, though, was that every month, he would write an editorial as Editor of the *Journal of the American Academy of Audiology*. I remember looking forward to understanding what interested him and what he saw as important in the work of others. I had the same anticipation as I was reading this book. I was there for a part of it, and I still found it interesting to see it through his eyes.

The book begins with a chapter on the early years of diagnostic audiology. It is interesting on any number of levels, but I tried to imagine what it must have been like back in the days before computers, signal averaging, or radiologic imaging. His description of the approaches to the diagnostic questions is fascinating and, in particular, why he pursued loudness measures. It seems quite likely that it has been a while since the last publication of a Békésy audiogram, but you will see one in this chapter. Perhaps I never quite understood, or I had just forgotten, how rapidly a disordered auditory system can undergo adaptation. It made me wonder if some of the difficulty we have now in pinning down pure-tone thresholds on patients with auditory neuropathy might be related to how rapid this is in an asynchronous system. The chapter also includes a discussion of the Synthetic Sentence Identification (SSI) test. Students of speech audiometry should go back to the early work of Speaks and Jerger to learn why they chose the targets and competition for this test. The test might seem quirky, but it had the strikingly real advantage in that it actually worked as an effective clinical tool for identifying retrocochlear disorder and APD.

The second chapter is on immittance audiometry and, in particular, the contribution of the acoustic reflex measurement and reflex patterns to auditory disorder diagnosis. It is a testament to Jerger's clinical observation that his tympanogram typing has proven to be universally applicable 50 years later. I am impressed that, even today, the combination of vector tympanometry and acoustic reflex thresholds remains the best way to identify stiffness disorders such as otosclerosis. Heroic efforts to harness other tympanometric measures have consistently led to overly sensitive measures from a clinical usefulness perspective. And today, acoustic reflex patterns have become an integral component of the early diagnosis of third-window disorders.

Each of the chapters in this book provides an insider's view to Dr. Jerger's thinking about the topic, a smattering of the data gathered, and a case or two to drive home the point. Other chapters include the topics of auditory processing disorder, binaural hearing aids, and the complexity of auditory aging. Two fascinating chapters cover his work on auditory event-related potentials. If you are not up to speed on any of these areas, you will be after you read Jerger's eloquent summary of each.

I want to tell another story about the patient described in Chapter 3 on APD and the cued-listening measurement described in Chapter 6. I had the privilege of working in the lab at the time this patient was being evaluated and this measurement technique was being developed. I'll give you a brief preview. The patient with APD has an isolated, well-described dichotic deficit. In the cued-listening measurement, continuous discourse is played simultaneously from a speaker on both the right and left sides of the patient. The task is a very simple one that you will learn more about in Chapter 6. This particular patient performed well on the task in quiet. When noise was introduced, however, she had the perception that the sound coming from the left speaker was attenuated. We were astonished at what appeared to be a sound-field reflection of that dichotic disorder. That is how Jim Jerger learned—from patients. And that is how he tried to teach us to learn.

As I reached the final chapter of this book, I was bemused by a story about one of my favorite Jerger articles, entitled "Normal Audiometric Findings." I cannot remember if I ever knew the story behind the article or if I had just forgotten. Recently, I have resurrected a talk about the importance of the test battery approach to diagnostic testing as the result of identifying a patient with a sizable eighth nerve tumor based on acoustic reflexes and screening for speech-recognition rollover. I remember someone in the audience saying that "we never see patients with tumors." And I remember thinking to myself, "and you never will, because you choose not to look for them." In today's world, we call that kind of thinking and testing confirmation bias. The story behind "Normal Audiometric Findings" was in response to that sort of confirmation bias. What Dr. Jerger shows is that you will see all kinds of interesting outcomes if you just look for them.

Among my favorite articles written by Dr. Jerger is one not referenced in this book. He wrote it in 1962, and it was entitled "Scientific Writing Can Be Readable" (*ASHA*, April 1962, pp. 101–104). If that sounds in any way pretentious, you can only imagine what the academics of the day must have thought of this precocious young whippersnapper. Regardless, in it he says, "You cannot communicate your research findings to other people unless you write about them in a way that allows other people to understand what you are talking about." In this book, Jim Jerger lives up to his own lofty expectations and provides a treasure trove of insight for anyone who is a student of diagnostic audiology.

—Brad A. Stach

Introduction

History is philosophy from examples.
Ars Rhetorica—Dionysius of Halicarnasius

Over a period of some 64 years, my colleagues, students, and I have completed research projects in a number of areas impacting audiology practice. We studied the diagnostic evaluation of persons with auditory disorders, ranging from the middle ear to the auditory centers in the brain. We reported these studies to our colleagues in 11 books and 335 articles, appearing in both audiology and otolaryngology publications. From these many sources, I have chosen to comment on articles and books representing 10 distinct areas of investigation.

I have tried to avoid excessive technical detail. Readers will find no soporific statistical test results, no *p* values, no details of instrumentation, and few references to anyone else's work. Readers are expected, however, to have a basic understanding of auditory evoked potentials and auditory event-related potentials. And, a sense of humor is always welcome.

My hope is that this historical overview will convey to students new to the profession something of the satisfaction associated with an audiology research project. Another goal is to remind those few who can still remember the 1950s and 1960s how research in those years impacted and shaped the early formative development of the profession. This is, in many ways, the story of the evolution of diagnostic audiological assessment and a record of how thinking has evolved over the years.

The book is divided into three major sections: (1) the early years, (2) the Baylor College of Medicine years, and (3) the University of Texas years. The early years included 9 years at Northwestern, shuttling between the School of Speech in Evanston and the Medical School in downtown Chicago. We left Chicago in 1961 to move to Washington, D.C. Here I spent one year, both at Gallaudet College and at the VA outpatient clinic. At Gallaudet, I learned about deafness and the incredible accomplishments of those wonderful young students. At the VA, I was one-third of a triumvirate, including Laszlo Stein and Stan Zerlin. We set the VA record for length of lunch break, which remains unbroken to this day. In 1962, we moved again, this time to Houston, where I served as head of research for the next 6 years at the Houston Speech and Hearing Center.

In Houston, with Chuck Speaks and my wife, Susan Jerger, we spent much of our time on the development and evaluation of the Synthetic Sentence Identification (SSI) materials. Then, Chuck went up to the University of Minnesota and crafted a distinguished career in speech science. In 1968, Susan and I moved from the Houston Speech and Hearing Center across the street to the Baylor College of Medicine, within the Texas Medical Center, where we spent the next 29 years.

Chapters 2 to 7 describe only a small fraction of our many interests during those 29 productive years, from 1968 to 1997. Finally, Chapters 8 and 9 cover some of the auditory event-related potentials studies we accomplished during the next 17 years at the University of Texas at Dallas. Chapter 10 fleshes out some odds and ends to complete the book. If you are interested in the right ear advantage, be sure to read the section, "A Visit to Montreal." Even if you're not, read it anyway. It is very interesting.

Now Susan and I have been retired in Lake Oswego, Oregon, since 2014, and are loving it. But we miss many old friends.

Acknowledgments

If these studies have been useful to the profession, major credit must go to the many colleagues and students who made the individual studies possible: first, my colleague, wife, and helpmate for the past 57 years, Susan Wood Jerger. Her influence can be found throughout the publications cited in this book.

At Northwestern, I welcomed the friendship and assistance of my mentor, Raymond Carhart, and of faculty members John Gaeth, Helmer Myklebust, Charles Lightfoot, and my dear friend and golfing buddy, Tom Tillman. At the Northwestern University Medical School, otolaryngologists George Shambaugh Jr., Gene Derlacki, and George Allen provided welcome support for our research in the audiology clinic.

At the Houston Speech and Hearing Center, Charles Speaks brought his expertise in speech science to our collaboration in the development of the SSI test materials. We were ably assisted by Carolyn Malmquist, Jane Trammel, and James Thelin.

At the Baylor College of Medicine in Houston, 29 fruitful years of research were facilitated by the active direction and cooperation of Bobby R. Alford, chair of the Department of Otolaryngology and Communicative Sciences. His dedication to the success of our laboratory over almost three decades never faltered. Memorable graduate students during those years included John Allen, Denise Brown, Robert Fifer, James Hall III, Maureen Hanley, Deborah Hayes, Susan Jerger, Karen Johnson, Craig Jordan, William Keith, Henry Lew, Brad Stach, Lois Sutton, and Ann Thompson. Otolaryngologic collaborators included Newton Coker, Mickey Stewart, and Makato Igarashi. We were ably assisted by a support staff including Larry Mauldin, Rose Chmiel Hardcastle, Sharon Smith, Terry Oliver, Connie Jordan, Emily Murphy, and Louise Loiselle. International visitors included Neil

Lewis from Australia, Joan Grant from New Zealand, Ali.A. Ali from Egypt, and Anestis Psifidis from Greece. I will always be grateful to neuropsychologist Fran Pirozzolo for his invaluable contributions to our studies of auditory aging and to Charles Berlin and his staff at LSU Medical School for their development of the Dichotic Sentence Identification (DSI) test, based on our SSI materials. In our work on binaural interference, we have collaborated closely with Shlomo Silman at Brooklyn College and Carol Silverman at CUNY. Their earlier work on auditory deprivation was related to subsequent concepts underlying theoretical explanations of binaural interference.

Finally, at the University of Texas at Dallas, we were indebted to Bert Moore, dean of the School of Behavioral and Brain Sciences, for his generous support of our AERP research efforts. We were ably assisted by graduate students Tara Davis, Rebecca Estes, Ralf Greenwald, Jeffrey Martin, Jyutika Mehta, Deborah Moncrief, Mary Reagor, Gail Tillman, and Ilse Wambacq.

I would be remiss if I did not reiterate the critical role that colleague Brad Stach played in the founding of the American Academy of Audiology, in addition to his many other accomplishments during the Baylor years. Finally, the work on AERPs at UT Dallas would not have been as successful without the important contribution of colleague Jeffrey Martin.

Abbreviations

ABLB	Alternate binaural loudness balance test
ABR	Auditory brainstem response
AERP	Auditory event-related potential
AFSC	Aerospace Medical Division
AKA	Also known as
ALS	Advanced life support
AMLR	Auditory middle latency response
ANOVA	Analysis of variance
APD	Auditory processing disorder
BCM	Baylor College of Medicine
Bell Labs	Bell Telephone Laboratories
CELF	Clinical Evaluation of Language Function
CLT	Cued Listening Test
CNS	Central nervous system
CP3	Left centro-parietal electrode
CVC	Consonant-vowel-consonant
dB	Decibel
dBA	Decibels on the A scale of a sound level meter
d′	Detectability index
E800	Grason-Stadler self-recording audiometer
DSI	Dichotic Sentence Identification test
EEG	Electroencephalographic
EMS	Emergency medical service
HTL	Hearing threshold level

Hz	Hertz (frequency in)
k	1,000
JND	Just noticeable difference
LE or L	Left
LEA	Left ear advantage
LPC	Late positive component
Max	Maximum
MCR	Message-to-competition ratio
Min	Minimum
MLR	Middle latency auditory-evoked response
ms	Millisecond
MNI	Montreal Neurological Institute
N1	Negative peak at about 100 ms on the evoked potential waveform
P2	Positive peak at about 200 ms on the evoked potential waveform
PZ	Midline parietal electrode
PAL	Harvard Psychoacoustic Laboratory
PB	Phonemically balanced
PBK	Phonemically balanced kindergarten list of words
PB50	Phonemically balanced 50-word lists
PI	Performance versus intensity
PN	Processing negativity
PTA	Pure-tone average
RE or R	Right ear
SCAN	Screening test for auditory processing disorder
SISI	Short Increment Sensitivity Index
SL	Sensation level
SPIN	Speech Perception in Noise Test

SPL	Sound pressure level
TTC	Token Test for Children
USAF	United States Air Force
UTDallas	University of Texas at Dallas
USPHS	United States Public Health Service
W-1	List of Spondee words
WISC	Wechsler Intelligence Test for Children
WWII	World War II

This book is dedicated to the memory of Sadanand Singh,
speech scientist, whose influence on our profession
will never be forgotten.

1

The Early Years

A DIAGNOSTIC CHALLENGE

Before the advent of brain imaging techniques, unilateral hearing loss in adults, either sudden or gradual, presented a diagnostic challenge. Meniere's disease and acoustic tumor are two examples of the problem. Meniere's disease results from abnormally high endolymphatic fluid pressure within the cochlea. It produces the distressing physical symptoms of unilateral hearing loss, dizziness, tinnitus, and nausea. Acoustic tumor (tumor affecting the eighth cranial nerve) derives from a schwannoma initially growing on the vestibular portion of the eighth nerve. As the tumor grows, it eventually invades the auditory portion of the nerve. The two etiologies initially produce roughly similar unilateral pure-tone audiometric patterns—relatively flatter in Meniere's disease, usually more sloping from low to high frequencies in acoustic tumor—but the audiogram difference, by itself, is not sufficiently predictable to be useful diagnostically.

Although Meniere's disease is not a pleasant experience, it is usually not life threatening, but a growing tumor in the auditory canal can, eventually, affect nearby brainstem systems responsible for basic life functions such as breathing. It is understandable, therefore, that in the 1950s, before the advent of sophisticated brain imaging, it would have been desirable to know with some certainty which of the two possibilities was, in fact, the more likely case.

The first suggestion that audiometric testing might provide an answer came from three British investigators, M. R. Dix, C. S. Hallpike, and J. D. Hood. Their 1948 paper in the *Proceedings of the Royal Society of Medicine* had a profound effect on the fledgling field of audiology. Dix et al. administered a loudness recruitment test, the alternate binaural loudness balance (ABLB) test, to 30 patients with unilateral Meniere's disease and 20 patients with unilateral acoustic tumor.

The ABLB test is a procedure in which the listener equates the loudness of a pure tone in each ear by adjusting the loudness of the tone on one ear until it equals the loudness of the same tone on the other ear, as the tone alternates between the two ears. In the case of Meniere's disease, Dix et al. found that, as loudness increased in the good ear, there was a concomitant increase in loudness in the impaired ear, but the equivalent increase in loudness on the impaired ear appeared to be compressed into a much smaller span of intensities. They attributed this compression of loudness to the phenomenon of "loudness recruitment," long recognized as common in persons with sensorineural hearing loss, especially in the high-frequency region above 1 kHz. But in the case of patients with acoustic tumor, there was no compression of the loudness range on the impaired ear. As intensity increased, loudness appeared to grow at the same rate on both the better and the poorer ears. In other words, patients with acoustic tumor showed little or no recruitment of loudness. Dix et al. concluded that loudness recruitment, as measured by the ABLB test, was characteristically present in their patients with Meniere's disease but characteristically absent in their patients with acoustic tumors. The implication seemed clear. You could distinguish between inner ear and auditory nerve sites of disorder by testing for recruitment. Its presence suggested an inner ear site while its absence pointed toward a site involving the auditory nerve.

Professor Doctor Eberhart Lüscher

There was one major problem, however. The ABLB test was only feasible if the hearing loss was unilateral. The unaffected ear had to be relatively normal. But a Swiss otologist, Professor Doctor Eberhart Lüscher, immediately grasped the long-range significance of their findings. If you could devise a loudness recruitment test that did not require one normally hearing ear, reasoned Lüscher, you could expand the diagnostic value of the loudness recruitment phenomenon to include persons with bilateral sensorineural hearing loss as well as unilateral loss, a potentially major advance in the audiological evaluation of virtually all sensorineural hearing disorders.

Influenced by the 19th-century psychophysical research of German scientists Ernst Weber and Gustave Fechner, on the measurement of just-noticeable differences (JNDs) in the loudness of tones, Lüscher reasoned that, if loudness grew incrementally by the accumulation of JNDs, then each JND must be smaller in the ear with loudness recruitment since so many of them seemed to be packed into a much smaller range of intensities. The answer, Lüscher reasoned, was to measure a patient's JNDs for loudness, which could be done on one ear independently of the recruitment status on the opposite ear: The ABLB requirement of unilateral loss would no longer be necessary. This reasoning did not hold up under subsequent research. Loudness in a listener with sensorineural hearing loss is much more complicated than a simple sum of JNDs. But, despite its faulty theoretical basis, the concept worked in practice.

Lüscher next devised a method for measuring the loudness JND in the clinic. As a student of psychoacoustics, he turned to the classical method of constants. He instructed his lab assistant, a young Polish engineering student named Jozef Zwislocki, to fabricate a device that would allow the operator to vary the degree of amplitude modulation of a pure tone generated by an audiometer. Zwislocki, a Polish immigrant to Switzerland, subsequently immigrated to the U.S., studied at the Harvard Psychoacoustic Laboratory, and then moved on to Syracuse University, where he eventually became a distinguished auditory neuroscientist. Zwislocki died in 2016 at the age of 96.

Lüscher reasoned that the smallest degree of amplitude modulation that the patient could just notice was a measure of the JND for loudness. In Lüscher's methodology, modulation was varied randomly over a range of 0 to 5 dB in a series of trials separated by silent intervals. The JND was defined as the modulation level corresponding to the 50% correct point on the psychophysical function relating percent correct performance to modulation level. You can imagine that after this procedure had been administered across three or four frequencies, both the tester and the listener were exhausted, but results were encouraging. After testing his method in the clinic, Lüscher concluded that his technique worked very well and could be viewed as a substitute for the ABLB as a test for loudness recruitment in patients with bilateral sensorineural losses. His results were published in the *Journal of Laryngology and Otology* in 1951. But word of his work had already spread among otology circles in Europe. An electronics company in London, Amplivox, was impressed with Lüscher's paper and thought there might be a market for a device that one could attach to an audiometer to produce the amplitude modulation that formed the basis for the test. My mentor, Raymond Carhart, ordered one of the units for use in the Northwestern audiology clinics. Since the unit was small, light, and portable, it could be carried between the School of Speech in Evanston and the Department of Otolaryngology at the NU Medical School in downtown Chicago. At a meeting of the graduate students, Carhart asked whether any one of us was interested in trying it out. I immediately volunteered and took my first halting step into a career in audiological research.

I was just beginning work on my master's degree at Northwestern when Lüscher's paper appeared. I took the Amplivox device to the Northwestern University Medical School in Chicago's near northside, hooked it up to an audiometer, and began to examine patients with hearing loss. After testing 89 individuals with various auditory disorders, I analyzed the data, wrote a paper based on the findings, and submitted it to the audiology faculty as a master's thesis. I then prepared a shortened version and submitted it for publication in *The Laryngoscope*.

My findings were in good agreement with Lüscher's. We had both demonstrated that patients with cochlear site of disorder appeared to have smaller JNDs for sound intensity than patients with either eighth nerve or more central sites. In addition, in my study, persons with more central sites appeared to