Experiments in Hearing

Georg von Békésy

Originally published in 1960; Reprinted in 1989

TABLE OF CONTENTS

Preface to the Reprint Edition

George von Békésy's *Experiments in Hearing* is one of the classics in the literature on hearing and may be regarded as the 20th-century equivalent of Hermann von Helmholtz's 19th-century *Die Lehr von den Tonempfindungen*. Like Helmholtz, Békésy dedicated himself to both the psychology and the physiology of hearing, but unlike Helmholtz, did not have to content himself with theoretical physiologizing based on the scant anatomical and physiological evidence of the mid-19th century. Thanks to the rapidly developing electronic and electroacoustic technologies, he was able to undertake pioneering physiological experiments. When doing so, he confirmed some of Helmholtz's hypotheses and disproved some others.

One of the most important hypotheses he confirmed was what become known as the "place theory of pitch perception." As an extension of Johannes Muller's doctrine of specific nerve energies, Helmholtz postulated that subjective pitch is determined by the group of auditory nerve fibers that is maximally excited and that the group depends on the location of the maximum vibration of the basilar membrane in the cochlea. According to Helmholtz, high audible sound frequencies produce such a maximum in the cochlear base, where sound enters the cochlea, and lead t the sensation of high pitch. As the sound frequency is gradually lowered, the maximum moves toward the other end of the cochlear canal at the cochlear apex, and the pitch becomes lower. Békésy demonstrated experimentally that the vibration maximum exists and that its location depends on sound frequency roughly according to the same function as does subjective pitch. However, Békésy discovered that the maximum arises in the presence of traveling waves, contradicting Helmholtz who seems to have thought that the maximum resulted from simple resonance. For this and related work Békésy received the 1961 Nobel Prize in Physiology or Medicine, the only Nobel Prize ever bestowed for research on the auditory system.

Békésy never resolved the question of the mechanism behind the cochlear vibration maximum. As late as in 1960 he wrote "From the first observations of the vibration of the cochlear partition it was clear that they presented a system about which physical science provided little knowledge and that many years would be required to understand it clearly." The fact that mathematical analysis based on well established physical principles had by then clearly shown how the cochlear vibration maximum can arise in the presence of traveling waves points to Békésy's great distrust of mathematical theories, which earned him the reputation of a rugged empiricist. Békésy was one of the leading exponents of the revolution that took place in his time against 19th-century armchair theorizing, and much of his work was dedicated to replacing sometimes unrealistic theories with experimental evidence.

Békésy was far too creative to be confined to sheer empiricisim, however, and ventured some hypotheses of his own. Perhaps the most germinal of them was his application of the visual phenomenon of contrast to sound analysis in hearing. It was aimed at resolving the classical paradox of an extremely sharp frequency analysis performed by the auditory system in the presence of fine time resolution. It is well known that sharply turned physical systems have long onset and decay transients, and Helmholtz's place theory, based on mechanical resonance, ran into sharp controversy because it failed to resolve the paradox. Békésy's observations on postmortem ear preparations and on models indicated that the mechanical vibration maximum in the cochlea was quite flat. This was compatible with short transients and good time resolution but not with sharp frequency analysis. He suggested, therefore, that the coarse cochlear frequency analysis was refined in the nervous system by means of lateral inhibition that led to contrast formation. Much research was devoted to the problem of the neural refinement of auditory frequency analysis, but its role is not yet clear. On the other hand, Békésy's hypothesis provided a trigger for Hartline's extensive investigations of lateral inhibition in vision. Hartline received the 1967 Nobel Prize in Physiology or Medicine for this and related work.

Although Békésy is best known for his physiological research, he also made pioneering contributions to psychophysics, where he transcended the confines of hearing and invaded the senses of touch and sight. Perhaps his best known and influential contribution to psychophysics was his invention of an automatic method for recording sensory absolute and differential thresholds. Because the method made it possible to track a threshold as a function of time or another physical parameter, S.S. Stevens called it a "tracking method." It was used for many years in research, and still is, on occasion, and received wide acceptance in clinical testing of hearing. Subsequently, in combination with the forced-choice procedures, it gave rise to various types of psychophysical methods subsumed under the name of the adaptive methods. They are the great favorites of contemporary psychophysics.

Experiments in Hearing is not a monograph but rather a compilation of Békésy's published research papers. The compilation is not strictly chronological, however, but is set in a logical framework. Within this framework, the papers ten to be arranged chronologically but, because of Békésy's systematic approach to research, the chronology does not violate logic. As a consequence, *Experiments in Hearing* does read like a monograph. This impression is strengthened by its organization into topical sections and into topical chapters within the sections. The first two introductory chapters were written especially for the book and the remaining two chapters of the introductory section were abstracted from the original papers and presented as separate entities.

The first chapter, entitled "The Problems of Auditory Research," reveals some of Békésy's research philosophy and experience. It is here that he classifies research problems and refers to "The embarrassing question, commonly arising at meetings in the discussion of a paper, and rarely serving any useful purpose." It is also here that he refers to the usefulness of professional enemies and complains about losing his three best ones who eventually became his friends. Békésy never mentioned their names but, from conversations with him, I strongly suspect that Hallowell Davis and Glenn Wever were two of them.

The second chapter concerns a very abridged but richly illustrated history of anatomical work on the organ of Corti in the cochlea. It is interesting to learn what Békésy considered to be the correct representation of the organ--what seemed correct in his time does not necessarily appear correct today.

The remaining introductory chapters describe some of the methods and instruments Békésy developed, and reveal his unique ingenuity. They include anatomical, physiological, electroacoustical, and psychophysical instrumentation, and should be an inspiration to creative laboratory scientists and perhaps to engineers as well.

The remainder of the book is concerned with the substance of Békésy's research. It begins with sound transmission through the middle ear and the skull bones, and then switches somewhat surprisingly to the psychoacoustics before returning to sound transmission and following the sound into the cochlea. The mechanics and electrophysiology of the cochlea are described to the limits of the knowledge of Békésy's era, much of it contributed by Békésy himself.
Many of Békésy's observations and measurements have been superseded, but before this happened, they provided not one but several stepping stones for the research that superseded them. *Experiments in Hearing* contains some of the most vital roots of our contemporary auditory knowledge and should be considered obligatory reading by all those who want to claim literacy in auditory science.

Jozef J. Zwislocki
Distinguished Professor of Neuroscience
Institute for Sensory Research
Syracuse University

Preface to the First Edition

This book brings together in one volume the chief results of a series of experimental studies on hearing and related problems extending over a period of 34 years. The earlier experiments, from 1924 to 1946, were carried out in the Royal Hungarian Institute for Research in Telegraphy in Budapest, those in 1947 in the Department of Telegraphy and Telephony of the Royal Institute of Technology in Stockholm, and the ones since that time in the Psycho-acoustic Laboratory of Harvard University. I am deeply grateful to the directors and staffs of all these institutions, and especially to Professor S.S. Stevens and Professor E. B. Newman, for their generous provision of facilities and technical help. In my work at the Psycho-acoustic Laboratory I am especially indebted to Mr. Ralph Gerbrands and Mr. Rufus L. Grason for their assistance in the development of mechanical and electrical equipment, to Miss Geraldine Stone for aid in the preparation of the papers published in English, and to Mrs. Elizabeth Gardner for her work in the production of drawings. Research in hearing is of such a complex and exacting nature that it would be difficult to proceed without advantage of the knowledge and skills of many other persons.

The original articles appeared in numerous technical journals, access to many of which is now difficult. More than half of them were written in German, the others in English, and all necessarily adhered to the special requirements of the various journals and editors. For this book the German articles have been translated into English, and all have been edited to produce a uniform style.

For this work I am indebted to Professor E. G. Wever, and it is proper to say that this presentation was made possible by his willingness to assume the task. Probably many persons cannot appreciate the labor that is involved in an undertaking of this kind to the extent that I do, who have shifted about in this troubled world to so

many countries and have learned and forgotten so many languages. It is almost a unique privilege to have this aid from someone working in the same field of research and conversant with its problems and technicalities.
It should be emphasized that the presentations adhere to the original articles, and the interpretations of problems and results reflect the evidence at hand when the research was carried out. In one or two instances, when later work has led to a change in viewpoint, this fact is pointed out in a footnote. Also a few typographical and other errors have been corrected.

The articles are grouped by subject, and the arrangement bears only a limited relation to the temporal order in which the experiments were performed. Part 1 is introductory. It presents two short chapter of new material on the nature of auditory problems and the historical development of our knowledge about the anatomy of the ear, and then includes two other chapters on anatomical techniques and experimental methods. The technical material of these last two chapters has been extracted from the experimental articles and assembled here so as to avoid needless repetition later on. The remainder of the book consists of the articles in their original form except for the extractions just mentioned and a few other deletions that are referred to at the proper places. Part 2 is concerned with the process of sound conduction in the ear, Part 3 with several aspects of the psychology of hearing, and Part 4 with the mechanical and physiological processes of the cochlea and its associated nervous system.

I should like to express my deepest gratitude to Suzanne Wever for the typing of the manuscript. The care and precision with which she performed this task contributed greatly to reduce the number of errors.

Georg von Békésy

Experiments in Hearing Standardization of a test of speech perception in noise. Jan 1960. 32-48.Â Subjects with hearing impairment in the high frequencies were particularly impaired by the masking caused by their own voice. The implications for multilogue conversations and auditory rehabilitation are discussed. View. GBI mean scores for all items in both groups were all above 3, suggesting quality of life improvement in conductive and mixed hearing loss patients. BP100 users showed a greater clinical gain in the APHAB global score and subscales compared with Divino users. In conclusion the BAHA provides significant auditory gain, subjective audiological benefits and improves quality of life in all BAHA users. In the experiment, two participants (one secretly an actor and one an unwitting test subject) were separated into two rooms where they could hear, but not see, each other. The test subject would then read a series of questions to the actor, punishing each wrong answer with an electric shock. Though many people would indicate their desire to stop the experiment, almost all subjects continued when they were told they would not be held responsible, or that there would not be any permanent damage. Hearing, Stanley Gelfand, Marcel Dekker, 1981 Experiments in Hearing, G. von Bekesy, Wiley, 1960 Noise Control for Engineers, H. Lord, W. Gatley and H. Evensen, Robert Krieger, 1987. Some Interesting Web Sites: http://www.boystown.org/cel/cochmech.html - Boystown National Research Hospital. educational pages on cochlear mechanics. NOISE CONTROL. Fundamentals of Hearing 4/30/01 2.2.