HEARING

A

21st Century Paradigm

Including Excerpts from
THE ELECTROLYTIC THEORY OF THE NEURON

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Hearing Concepts
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Overview of the Chapters

1. Introduction to Biological Hearing .......................................................... 1
   A review of the state of hearing research at the current time and discussion of the tools
   needed to move the field forward.

2. The configurations of the hearing modality .............................................. 29
   A detailed look at the scope of the human hearing system and the materials and
   techniques used to implement it.

3. The Electrolytic Theory of the Neuron/Synapse ...................................... 65
   The first application of the electrolytic theory of the neuron to hearing and a review of the
   new insights available. This new paradigm replaces the chemical theory of the neuron.

4. General and Inner Ear Physiology .......................................................... 109
   The first presentation describing the detailed operation of the labyrinth, cochlea and
   cochlear partition based on first principles. The new paradigm based on acoustic
   dispersion within the tectorial membrane replaces the prior, largely conceptual,
   resonance within the basilar membrane paradigm developed most broadly by von
   Bekesy. The new paradigm is the first to offer any explanation for the rapid attenuation
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PREFACE

"Neurophysiology has at times been described as data-rich and theory-poor. The neurophysiology of hearing however may almost be described as speculation-rich and data-poor. There is a serious lack of systematic data at virtually every level of the auditory system."

N. Y-S. Kiang, 1965

The above quotation from Kiang, in spite of his efforts and those of others, has changed little in the last fifty years. No subsequent work could be found in the literature satisfying Kiang's call for action. In 1998, Poon & Brugge confirmed this situation. "The full power of combining experiment and theory has yet to be unleashed on studies of the neural mechanism in the brain involved in acoustic information processing." The goal of this work is to provide the theory that explains the previously collected data and guides the next data collection cycle; this is the essence of the scientific method.

This book is complementary to the author's 2004 work, Biological Vision: A 21st Century Tutorial. It was planned to write a book on the broader subject of the neural system. However, it was quickly found that detailed knowledge of the other sensory modalities was as sparse as it had been for vision. It was not possible to write a book on the neural system that was both detailed and comprehensive. This work provides a new and both comprehensive and contiguous description of the auditory modality. A new paradigm is introduced. This paradigm introduces several new propositions incompatible with previous works.

1. It introduces the actual mechanism of frequency analysis used in biological hearing for the first time.
2. It describes in detail the circuits of the sensory neurons that create the generator waveforms at their axons.
3. It also describes the method of percept creation used in both hearing and vision for the first time.
4. It also provides the first explanation of the mechanism resulting in the poorly named "critical bands" in hearing, and it ties this mechanism to the attention mechanism.
5. It defines the method of encoding used at the lowest level within the neural system and shows that the commonly used PST histogram is inappropriate while defining a new histogram format.
6. It shows a literal interpretation of the clinical term recruitment is inappropriate.

As noted by Kuhn when he expanded the concept of paradigm, "rival paradigms are incommensurable—that is, it is not possible to understand one paradigm through the conceptual framework and terminology of another rival paradigm." A feature of a new paradigm is its frequent ability to explain paradoxes encountered in the old paradigm. Both the fundamental frequency paradox and the illusory paradox associated with the old paradigm are resolved under the new paradigm. The unresolved role of the outer hair cells within the cochlear partition under the old paradigm is clearly defined under the new paradigm, as is the operation of the cochlear partition itself. The new paradigm does not require, or support, a mechanical amplifier between the basilar membrane and the cilia.

As noted in Chapter 1, the material prepared to describe the contiguous hearing modality greatly exceeds the available space in a one volume book. As a result, this volume may appear too cryptic or overly concise in some areas. To alleviate this problem, a more verbose version of this work (that may expand into a second volume) was placed on the Internet in 2007. Where appropriate, the reader may wish to consider this volume a guide to that resource.

The overall effort was planned and written by one author to communicate a cohesive end-to-end description of the auditory system, primarily in humans, that is as complete and detailed as possible. Of necessity, the level is designed for advanced students and researchers in neurobiology, residents, and other professionals seeking current information on the biology of hearing. It originated during the preparation of a neurological text of larger scope when it became apparent that the operation of large portions of the auditory system were not adequately understood within the hearing community. It became apparent that much of the knowledge available from vision research could be applied to the auditory system.

This book could not have been written by an Insider of the Hearing research community. It would have required excruciating and wrenching changes from what I would have been taught, and what my associates would tolerate in the realm of Ideas. The ability of an "uninitiated" to review the available data and derive a comprehensive functional model appears to offer significant value in this situation. Uninitiated may not be an appropriate term since
the author has previously performed a similar analysis on the visual system and published the most comprehensive book available on its operation. Much of that material is available on the Internet and is accessed by thousands from around the world every day.

The above methodology has provided extensive insights that were not available to the exploratory investigators at the time of their experiments. These will be presented below. The hearing system shares many of the architectural features of the vision system. Reinterpretation of the available data within this realization offers considerable verification of the proposed model, along with improved understanding of the operation of the auditory system.

Eddins & Green have discussed the difficulty of developing a mechanistic theory of how the auditory system functions. They note the complexity of the system has made this a difficult task. The problem has been exacerbated by the wide range among experimental values for a given parameter found in the literature. They noted de Boer rejected all theories related to frequency analysis proposed prior to 1985 as ad hoc based on a limited data set. He proposed the community seek to replace the myriad of ad hoc models with a single, internally consistent “super-model.” This work will introduce a number of improvements in the data set since then as well as a paradigm shift in the fundamental assumptions related to transduction. It also introduces the Activa, the active electrolytic semiconductor device of the neural system. The discovery of the Activa provides a common explanation to many previously unresolved issues in all areas of the neural system. As a result, this work offers a much more comprehensive and internally consistent, although still incomplete, “super-model” for Professor de Boer’s consideration.

In reading the preface to “Foundations of Modern Auditory Theory” by Jerry Tobias (1972), I was intrigued by some of his thoughts. He notes, “For a long time now, I’ve been looking for a book that would tell me more about ears than I wanted to know. It doesn’t exist. This book isn’t it either, although it was devised for the purpose of filling more gaps than any of the others do.” Following his publishing adventure, he noted, “Anyone who attempts to compile a treatise of the magnitude of this one has to be an eccentric—if not when he starts, then certainly by the time he’s done.” Let me add that the likelihood of becoming an eccentric is compounded when one chooses to write all of the text, as opposed to only editing the work of contributors as Tobias did. After encountering the same problem in vision and solving it, I also wanted to find a desk reference that explained how hearing worked.

The task appeared to revolve around the penchant of biologists and even biophysicists to rely upon the linear assumption. Belgium & Copenhagen highlighted the awkwardness of the linear assumption in 1988. They described the logarithmic transfer function of the synapse graphically and in considerable detail, including using the expression “an e-fold change in the release rate of transmitter from the rod be obtained with a 2 mV change in rod potential.” They then transition to a linear two-terminal model for the synaptic mechanism in their figure 7.

The Electrolytic Theory of the Neuron presented in this work is not a variant of the passive linear concept of the synapse developed in earlier works. The Electrolytic Theory was developed from fundamental concepts, involves an active element and is inherently nonlinear (primarily exponential based on the mechanisms involved). It applies to all elements of the neural system, not just the synapse.

The original debate over the chemical versus electrical character of the synapse hinged on the unidirectional character of the signal flow in the face of a bilateral (linear) description of the electrical putative network. Patch clamp data is now available showing the synapse exhibits a diode characteristic that is electrically reversible. Such performance is compatible with the Electrolytic Theory of the Neuron but is in conflict with the current putative chemical synapse which is physically asymmetric and not reversible.

My middle name is Thomas. I am the quintessential “doubting Thomas” of folklore. I must be able to answer the four basic questions about anything I encounter and become involved with; what, where, how and why. This talent, or eccentricity, has served me well. It has provided answers to many previously unknown facts during my career. This has been particularly true about the visual system, documented in my recent book, and it has now answered many previously unanswered questions about the auditory system, documented in this work.

Attempting to proceed without a sophisticated model (as opposed to a simple conceptual model) is a direct violation of the Scientific Method. The disparate data in the literature can only be rationalized (or discarded as erroneous) based on an adequate (although possibly still incomplete) model. Lacking such a model, the data in the literature is necessarily “out of context.” At the current time, the field of hearing research must be considered one of exploratory research, rather than applied research. The primary goal of this work is to provide the necessary model, place the data reviewed in its proper context, and provide visibility into the appropriate future applied research.

The above methodology has provided extensive insights that were not available to the exploratory investigators at the time of their experiments. These will be presented below. The hearing system shares many of the architectural features of the vision system. Reinterpretation of the available data within this realization offers considerable verification of the proposed model, along with improved understanding of the operation of the auditory system.
Appendix A. However, it is designed for the upper university through postgraduate level. The initial chapter will present some material in abbreviated form, with subsequent detail to follow. As a result, those without at least an introductory course in the morphology and physiology of animals may find it difficult to follow. On the other hand, it will introduce many engineering and mathematical concepts that are foreign to both previous and current biology curricula. As a result, some material may appear new to even those well prepared in the biological sciences.

Chapter 2 is presented with the particular purpose of acquainting the reader with the Electrolytic Theory of the Neuron. Additional mathematical concepts will be introduced periodically as the need arises throughout the work. The mathematical field of conformal transformations has been found to play a crucial role in the ability of the visual system of humans to extract features from complex two-dimensional scenes imaged on the fovea. Among other features, a conformal transformation used in vision transforms circles in object space into straight lines in the correlation space of the occipital lobe. This work will show a similar Riemann transformation is used in hearing.

The paradigm shift embodied in the Theory and models presented in this work may be difficult for many teaching academics to accept. They are frequently wedded to the material they are currently teaching. To change their position requires wrenching changes related to both their thinking and the syllabi they have worked from for years. Unfortunately, their students do not suffer these constraints. The students have proven willing to adopt the material via their exposure to it on the Internet.

This work introduces a number of scientific disciplines to the study of hearing that did not exist during the first half of the 20th Century. These disciplines lead to an entirely different concept of the auditory modality than presented in the literature up to this very day. The method of energy propagation within the cochlea depends on the development of the recent field of liquid crystals (beginning in circa 1950), combined with the unique mode of energy propagation associated with the Rayleigh (surface acoustic) wave. The method of frequency selection employed in the cochlea was only recognized theoretically by Marcanti in 1969. The electrolytic nature of signal transmission within the neural system was first published by this author in 2004. Any study of hearing (whether theoretical or empirical) that does not incorporate the mechanisms associated with these technologies is obsolete, virtually by definition.

An earlier alternate electronic theory of the neuron (focused on the synapse) was suppressed by the oligarch peers of neurology during the 1950's and little material based on an electrolytic approach has been published since. This was, and remains, an unfortunate action by the neurological community. It has retarded the advancement of science concerning the sensory modalities significantly. The Electrolytic Theory of the Neuron (addressing the complete neurological system) is based on concepts concerning a state of matter unknown to the generation active at mid-century. The Electrolytic Theory of the Neuron is based on the liquid-crystalline state of matter. The liquid-crystalline state is becoming known as the fifth state of matter, following the solid, liquid, gaseous and plasma states. Currently, the success of the Electrolytic Theory of the Neuron is so advanced, it answers questions that cannot even be formulated based on the chemical theory. This fact will become overwhelmingly clear. In the course of interpreting this work and its companion work on neurology and biological vision.

The Electrolytic Theory easily handles the following questions. What is the main purpose of Reissner's Membrane within the cochlear partition (Chapter 4)? Why is there an electrical potential difference of 80 millivolts between the two sides of the membrane (Chapter 5)?

It also answers another unique question that has not been answered by any other theory. "What mechanism can provide 450 dB/octave attenuation on the high frequency side of a sensory neuron response than any resonance-based circuit?" This attenuation far exceeds that achievable in any resonant circuit (Chapter 4). The unique mathematics associated with this mechanism provides strong support for the theory of frequency separation proposed in this work.

The dispersive theory of the cochlea presented here has also significantly advanced understanding at the expense of the various resonance and other travelling wave theories of the literature. It answers many questions not answered by, or beyond the scope of, these other theories. A good example is "why is the frequency response of the dispersive mechanism asymmetrical when measured at the auditory nerve?"

The reader is also asked to examine his interpretation of how the Scientific Method should build on the foundation provided by earlier investigators. Should the early work be considered a spotlight defining a narrow path forward through the darkness, or as a floodlight providing the ability to interpret the environment immediately ahead in order to gain a broader understanding? The first approach necessarily prevents examination of branches in the road and the approach of parallel investigations from outside the narrow path that may lead to the merging of ideas, the very essence of progress in science.
This work probably contains errors and inconsistencies. It certainly contains unfinished tracts. The author has not had the advantage of students to proofread every page. While it has been circulated among qualified readers, any errors are the responsibility of the author and will be corrected as soon as possible via the author's website and in future editions.