Book Reviews

Man as Sensor

Sensory Inhibition. GEORG VON BÉKÉSY. Princeton University Press, Princeton, N.J., 1967. 277 pp., illus. $8.50.

This book is based upon the Herbert S. Langfeld Lectures delivered by von Békésy at Princeton University in the fall of 1965. Von Békésy's report of his own extensive experiments in the processes of sensory inhibition represents an important substantive and methodological contribution. On the substantive side, the formulation of the idea of "funneling" as a general principle underlying the inhibitory interactions that filter information from sensory receptors clarifies the relationships between phenomena of perceptual resolution, sensitivity, and integration. On the methodological side, it is appropriate that, in a period increasingly dominated by electrophysiological approaches to sensory research, the advantages and unique achievements of psychological experiments be explicitly stated.

Von Békésy's concern with inhibition goes back to 1928 and his study of the mechanical properties of the basilar membrane. Depending upon the frequency of vibration, different sections of the basilar membrane vibrate at maximum amplitude, but the maximum is relatively flat. In order to explain the precision of pitch discrimination, von Békésy suggested that the lateral fibers of the basilar membrane sharpen resolution by suppressing the response of all the nerves but those stimulated near the maxima. In 1930, he proposed that inhibition is also a factor in the perception of the direction of a sound. The inhibition that occurs in the basilar membrane and in directional hearing, however, differs in nature from the inhibition of motor responses, in that it is accompanied also by summation. Though a large binaural time difference localizes a sound completely in one ear, the loudness that is perceived is greater when both ears are stimulated than when only one ear is stimulated. Von Békésy conceives of this simultaneous action of inhibition and summation in sensory processes as a funneling of laterally spreading stimulation into a localized neural pathway. Funneling by filtering and amplifying the neural response serves the important function of increasing the signal-to-noise ratio.

Von Békésy's view of funneling is far-ranging and varied. He shows it to be a general characteristic of the nervous system that may occur at many different levels. Funneling is a function of the spatial and temporal distribution of stimuli, the magnitude, frequency, and abruptness of a stimulus, and the density of neural interconnections. The experiments he reports show that it affects sensitivity, resolution, and the integration of spatial and temporal patterns of stimulation. A large amount of funneling produces a low absolute threshold, a large difference threshold, a lower rate of increase in sensation magnitude with increase of stimulus intensity, and precise apparent localization. Pursued in depth, the processes of funneling raise many fascinating and fundamental questions.

A basic type of funneling action is that responsible for Mach bands. In Mach bands, a graded distribution of light is transformed into a much sharper distribution of sensation. Von Békésy demonstrates that Mach bands are not restricted to the eye but occur on the skin for both direct pressure and vibration. The basic effects of excitation and inhibition that produce Mach bands are derived from observations on the sensory impressions produced by two points of stimulation on the skin as their distance is increased. The summation of adjacent stimuli and the inhibition of more distant stimuli lead von Békésy to propose that every stimulus produces an area of sensation surrounded by an area of inhibition. This pattern of activity is basic to all sensory systems and constitutes a neural unit. The concept of a neural unit furnishes a unifying explanation for the phenomena of two-point stimulation and Mach bands. The properties of a geometric model of Mach bands on the skin and in the eye are examined in some detail. Von Békésy shows that if Mach bands are to occur the inhibitory area has to be larger than the sensory area, and that an adequate description of observed Mach bands is obtained if the size of the inhibitory area and the magnitude of inhibition are assumed to increase with the intensity of the stimulus. He also demonstrates that the proposed model is consistent with the occurrence of inhibition at one level or at successive levels of the nervous system, and that the dimensions of the neural unit determined for the skin and for the eye account for the differences between Mach bands on the skin and in the eye.

The funneling effects found in directional hearing as a function of the inequality of the magnitude or time of arrival of two sounds also has its counterparts in other sense organs. A difference of 1 millisecond is sufficient to localize a sensation of vibrations, taste, or smell as coming from the point from which stimulation arrives first. Moreover, the localization of vibration on the body may be shifted by introducing delays in activating two vibrators analogous to that which occurs in the dichotic localization of a sound, though the cutaneous receptors, unlike the auditory receptors, possess "local signs" that indicate spatial position. Even when two vibrators are placed in a vertical position on the same side of the body, it is possible to localize the sensation as coming from a point from which stimulation arrives first. Thus localization is not tied to interactions between the hemispheres. Only in experiments on warmth and pain has localization not appeared in time intervals as short as 1 millisecond. Von Békésy attributes this failure to his procedure, which produced a slow onset time for both these sensations. He shows auditory and cutaneous localization to be best when the onset of a stimulus is abrupt.

Speed of Transmission

Von Békésy's study of funneling expands into related topics. Since we do not perceive a large area over which traveling waves move when the body is stimulated by a vibrator, the funneling process in localization must be rapid and in the millisecond range. Change in localization as a result of delay of stimulation provides a means of measuring the speed of nerve conduction. Helmholtz used a reaction-time experiment to measure the speed of nerve transmission and found it to be between 50 and 60 meters per second. When localization is used to estimate the speed of conduction, the estimates are much greater. Von Békésy estimates the speed of transmission for vibrations on the skin to be 208 meters per second. He suggests that there are two speeds of neural conduction—a fast process for the inhibitory interactions that produce localization, and a slower process for the growth of a sensation. Whereas localization is determined within a few milliseconds after the onset of a stimulus, the time necessary for the growth of a sensation may take from 20 milliseconds in hearing to more than 1000 milliseconds in taste, smell, and vibration. Von Békésy found that the speed of neural transmission is greatly affected by temperature and pain. He reports that an electric shock applied 10 seconds before an observation will cause a significant drop in the speed of nerve transmission. The lower speeds reported from animal studies may therefore be due to the effects of anesthesia, temperature, and pain which disturb the nervous system.

Localization is a powerful method for probing neural activity. Cyclic changes in localization when the tongue is stimulated indicate a periodicity in taste sensations. Localization phenomena also divide the four basic taste sensations into two groups: sour-salt and sweet-bitter. Simultaneous stimulation of the sides of the tongue with bitter and sweet or sour and salt produces a single sensation in the middle of the tongue which can be moved from side to side by suitably timing the stimulations. A single sensation is not produced, however, for simultaneous stimulation with bitter and sour or salt and sweet. Thus there appears to be a closer relation between bitter and sweet and between salt and sour than between other pairs. An unusual type of neural funneling is shown when vibrators with frequencies of 20, 40, 80, 160, and 320 cycles per second are placed on the arm. Only the middle vibration of 80 cycles per second is felt. The presence of all the vibrators, however, increases the magnitude of the sensation through summation. This indicates that even a flat maximum may set into action inhibitory effects that produce a sharp localization.

Von Békésy's contrast of the use of psychological and electrophysiological methods to investigate sensory functions highlights the strengths and weaknesses of each approach. The limitations besetting each method make it important that sensory functions be studied by both electrophysiological and psychological experiments. Von Békésy suggests, for example, that localization of a stimulus is determined by the onset of nerve firing, the later firing serving to indicate the magnitude and quality of a sensation. The evidence here is psychological. A 2000-cycle-per-second tone can be determined quite well from only two cycles of vibration; similarly, localization of a vibratory pattern on the skin of the arm will occur when only two complete cycles are presented. This demonstrates the difficulty in using only electrophysiological methods to study sensory processes. Electrophysiologically, there is at present no means for separating the initial burst from succeeding spikes in neural transmission and for correlating initial bursts with the phenomenal property of localization and succeeding spikes with the properties of magnitude and quality. A central problem in the study of sensory processes is the relationship between neural responses and subjective attributes. Von Békésy's discussion emphasizes that any hypothesis about the neurophysiological correlates of sensory attributes must remain tentative in the absence of corroborating psychological experiments. Though not mentioned in the book, a most interesting divergence between electrophysiological and psychological studies concerns the question of coding taste. Electrophysiological measures indicate that there are no receptors that are specifically sensitive to taste qualities; rather, taste is determined by the pattern of neural activity. In contrast, von Békésy's psychological studies indicate that there are single receptors which are sensitive to specific tastes such as salt, sour, bitter, and sweet. It is possible that electrophysiological recordings from nerve fibers do not fully reflect the funneling action that occurs at higher levels of the nervous system, or that the taste system in man differs from that of animals. Whatever the final resolution of this issue, it reveals clearly that electrophysiological recordings must be shown to be consistent with psychological experiments before electrophysiological measures of neural responses can be interpreted unambiguously.

Experimental Methods

Von Békésy discusses the difficulties of using psychological observations in the analysis of sensory functions. The foremost requirement is that methods of stimulation produce a well-defined and constant effect. The book amply attests to the difficulty of this requirement and to von Békésy's skill in arranging experimental procedures that meet it. Von Békésy shows that psychology can be as precise in its methods as electrophysiology. Precise experimental control is not sufficient, however. The sensory effects produced by even a simple and precisely defined stimulus are often numerous, and the subject must be trained to report only on the particular sensation one is concerned with and to inhibit other sensations. A careful analytic description of the possible percepts may even be necessary. Perceptual experiments for the purposes of sensory analysis must be guided by an introspective attitude that reduces cognitive and motivational factors to a minimum.

Funneling and inhibition can also occur at a cortical level. A form of cortical inhibition is involved in the fact that we appear to observe discontinuously, taking in sensory information in temporal quanta. Through training one can also learn to inhibit stimulation. For example, a singer apparently can be trained not to hear the bone-conducted sounds coming from his throat and to hear his voice only through the air-conducted sounds. A complex case of funneling occurs in the projection of sensations outside the body. Von Békésy reports that when there is a time interval in stimulating the two knees with vibrators there is a jumping of sensation from one side to the other depending upon which knee is stimulated first. After several weeks of training, however, a subject can experience a continuous motion of the vibratory sensation from one knee to the other as a function of the time interval. Now when the knees are stimulated simultaneously, the vibrations are localized in the free space between them. Moreover, a displacement of the sensation in this free space will occur with suitable changes in the timing of stimulation. The projection of sensations into external space appears to be closely related to cortical funneling in ways that are not at all understood.

Von Békésy does not adopt a single viewpoint or comprehensive theoretical position toward funneling and inhibition processes. Rather, he shows the advantages of a many-sided investigation of these phenomena. The experiments presented succeed in demonstrating funneling and inhibition as processes common to different sensory organs and to different levels of the nervous system. The research reported thus discloses the commonality among diverse phenomena. The pulling together of different phenomena in a way that reveals similarities will provide stimulating insights not only to sensory physiologists and psychologists but also to those interested in more complex perceptual and decision processes. Von Békésy's research clearly fulfills the quotation from Goethe inscribed at the beginning of the book—*Willst du ins Unendliche schreiten geh nur im Endlichen nach allen Seiten.*

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Newton as an Elder Statesman

The Correspondence of Isaac Newton. Vol. 4, 1694–1709. J. F. SCOTT, Ed. Published for the Royal Society by Cambridge University Press, New York, 1967. 611 pp., illus. $38.50.

With the publication of this fourth volume the monumental Royal Society edition of the correspondence of Newton has now turned the corner toward completion of its seven volumes. It is very fortunate that J. F. Scott was available and willing to shoulder the heavy burden of continuing the work which had been carried so far by the late H. W. Turnbull.

The present effort covers the years 1694–1709, and since Newton's earliest letters were from 1661 the four volumes represent about three-quarters of his writing years (he died in 1709), leaving the next three volumes to contain the last quarter of years, the undated material, and the collected indexes and scholarly machinery. This fourth volume, though only slightly larger in pages than its predecessors, carries almost twice as many individual items. As a sign of the times, in the lapse of five years or so during the change of editors, the price of the volumes has jumped to half as much again; but then no standard library or specialist researcher on Newton and his period can afford to be without constant access to this fundamental work of the highest caliber.

The Newton that is found in the pages of this volume is already the elder statesman of science, reaping the just rewards of the *Principia* and beginning, seven years after its publication, to toy with the idea of extending it in a second edition. To continue his work with the fundamental lunar theory he had need of the observations of Flamsteed; and so developed one of the most famous and unpleasant altercations between scientists of great worth but incorrigibly prickly character. Further in the matter of rewards, Newton was appointed to his office at the Royal Mint, an office which was intended as a sinecure, but taken so conscientiously and seriously that one must credit quite a lot of the later economic strength and security of England to the efficient reforms and administration of Newton; perhaps one might suggest that the next Nobel prizewinner should be drafted to a similar "sinecure" in the office of Postmaster General. From the same period comes Newton's absolutely uneventful term as a Whig University Member of Parliament, and his being knighted, though exactly why he got these two honors still remains a rather dark mystery.

As usual with the Newton material—and we can expect nothing different from the remaining volumes—there is hardly a trace of the human being existing within this scientist shell. Even the tirade at Flamsteed, though violently angry, nevertheless maintains a certain impersonality. Just a touch of the triumphant mathematician may be seen in number 561, where he copies at length the challenge to solve the problems of the brachistochrone as just proposed by Bernouilli, then adds, "Thus far Bernouilli. The solutions of the problems are as follows. . . ." Perhaps most important is the interesting matter of number 695 and number 697, where Newton writes to Sloane to arrange for Francis Hauksbee, well-known inventor of electrical machines and of a fine new air pump, to bring his pump and demonstrate the phenomena of vacuum. What is interesting is that Newton suggests that Hauksbee come to his house where he can "get some philosophical persons to see his Expts who will otherwise be difficultly got together." It must be supposed from this that there is some possibility that a group of the Royal Society amateurs may have actually met at Newton's house; it gives an image far from that of the completely antisocial recluse.

Of more direct scientific interest in this volume, apart from the already mentioned and very extensive contributions to lunar theory, there is a fine dissertation on the quantifying of degrees of heat in the temperature scale, with astute experimental observations on melting points and other fixed marks in the range. To speak, however, of the matter of scientific content rather than the historical information of the letters must bring up another publication that has just started to come forth from the Cambridge University Press in their same superlatively competent style. The new series is that of *The Mathematical Papers of Isaac Newton*, of which the first of a projected set of eight volumes has just come out, edited by D. T. Whiteside [reviewed in *Science*, 13 Oct. 1967]. Now that we have both sets of Cambridge University Press volumes begun and a full variorum edition of the *Principia* long promised and on its way, we may take this passing of the halfway point of the *Correspondence* as a signal that Newton studies have now become very much an excitingly successful and full-time occupation for very competent people.

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Whither Queues?

Queuing Theory: Recent Developments and Applications. Proceedings of a NATO Science Committee conference, Lisbon, Sept.–Oct. 1965. R. CRUON, Ed. Elsevier, New York, 1967. 240 pp., illus. $13.50.

"Queuing theory" is a term of recent vintage (the 1940's) for mathematical studies of situations producing congestion and hence delays or waiting lines (queues). The typical mathematical model is that of a service system in which a stream of demands for service appears before a service center with one, or many, servers, and either the time epochs at which demands are made or the service time required, or both, have a probabilistic (stochastic) character. With the appearance of a flood of recent books, the study of this model in all its many guises, elaborations, and variations may be regarded