Meetings

Sensory Coding

A conference was held at Duke University 19–20 May 1967, to discuss the latest findings in the field of sensory coding. One of the long-standing controversies in sensory neurophysiology concerns the nature of mechanisms underlying the feeling of pain. One school of thought has held that pain is a separate sensory modality, mediated by specialized nerve endings. Against this view has stood the theory which held that pain is caused by strong stimulation of sense organs which also respond to innocuous stimuli.

E. R. Perl and his associates have now obtained evidence which clearly supports the first of the theories, at least insofar as cutaneous "fast" pain is caused by mechanical damage. In skin nerves of both carnivore and primate, they found afferent fibers which were excited only when the skin was pricked, crushed or cut, but not when the skin was touched, pressed by a blunt instrument, cooled or warmed, or exposed to abrasive chemicals. These fibers conducted at a medium velocity, indicating that their diameter lay in the so-called delta (or small myelinated) range and had sensitive spots in the skin distributed in a characteristic fashion. Other afferent fibers of the same or slightly larger caliber had a similar structure in the receptive region but were more sensitive. The fibers responded to moderate pressure so that the rate of discharge reached saturation before the stimulus produced overt damage. As a class, the afferent fibers with this characteristic structure of the receptive region required stronger stimulation for activation than any other type of cutaneous mechanoreceptor.

V. B. Mountcastle and his school are approaching the problem of "specificity" of sensory modalities from a different angle. They compared the behavior of receptor organs in the skin of monkeys with psychophysical data obtained from human subjects. The same stimulating device was used in both sets of experiments. The correlation function relating the indentation of skin to the discharge rate of slowly adapting cutaneous receptors matched precisely the psychophysical stimulus-sensation curves (Stevens' functions) of humans. Mountcastle also described two kinds of mechanoreceptors that adapt rapidly. These mechanoreceptors were studied by applying sine-wave vibrations of varying amplitude and rate to the surface of the skin. These two sets differ in anatomical location and in their properties. The vibration receptors, which lie deeper, in subcutaneous tissue, and which have an optimum response to higher frequency vibration, can be identified with a high degree of probability with Pacini corpuscles. When the vibrator was applied to the skin of human observers, two kinds of sensation were evoked. At lower frequencies this was felt as a superficial, precisely localized flutter; at higher frequencies the sensation was felt as a deep, diffuse vibration. The curves relating threshold amplitude of the subjective sensation of vibration (or flutter) to frequency of stimulation matched the curves relating the threshold of "entrainment" of vibration receptors of monkey skin. (By "entrainment" is meant one-to-one correspondence of the nerve discharge to the stimulating sine wave.)

The findings by Perl and by Mountcastle are in good agreement with the proposition that the quality—or modality, or meaning—of stimuli acting on the skin is encoded by the selective activation of specified nerve fibers in skin nerves. Their observations did not, to date, extend to the smallest, unmyelinated afferent fibers.

Perl and Mountcastle also obtained evidence that modalities remain segregated within the central nervous system. Mountcastle concluded further that the brain is a "linear operator" where the intensity of excitation of peripheral nerve fibers is precisely reproduced through successive stages of transmission and ultimately determines the intensity of subjective experience.

While strict segregation of sense modalities may be an essential feature of the blueprint of the structure in the dorsal column-lemniscal pathway, this principle does not seem to be incorporated in the phylogenetically probably older anterolateral (or spinothalamic) system. Convergence of modalities at thalamic and cortical points of projection of the spinothalamic pathway was discovered by Mountcastle and Poggio some years ago. P. D. Wall reported his studies of the synaptic connections and functional properties of neurons presumably performing the first stage of information-processing in the anterolateral system. According to Wall the information fed from the periphery into the spinal cord is translated into a temporal pulse code by the interaction of second-, third-, and fourth-order sensory neurons, located in Rexed's layers 4, 5 and 6 in the dorsal gray matter of the spinal cord. Convergence of cutaneous modalities is the rule in lamina 4; cutaneous and proprioceptive input is being mixed in lamina 6. The 4th, 5th, and 6th layers are under centrifugal (efferent) control. The location of the T cells of the gate-control theory of Melzack and Wall is probably in layer 5.

Wavelength discrimination in the visual system was discussed by R. L. De Valois. He reviewed the evidence accumulated over the past few years for the existence of three types of color receptors in the retina. The absorption spectra of the photosensitive pigments of the three types of cones are overlapping, but have distinct maxima. Retinal receptors are connected to ganglion cells, and then to neurons in the lateral geniculate nucleus in such a manner that one cone type excites, and another inhibits the same higher order afferent neuron. The result of these interactions is that neurons give opponent responses to pairs of wavelengths which we see as red and green, or yellow and blue, in the case of different neurons. About one third of the monkey lateral geniculate cells are "color-blind"; these are either excited when white light is turned on and inhibited when it is turned off, or vice versa. It is intellectually gratifying that these findings reconcile the color theories of Young and Helmholtz with those of

Hering, thus resolving a controversy nearing its centennial. At the same time a dozen or so minor contending theories have been eliminated from competition.

The organization of excitatory and inhibitory input from retina to lateral geniculate neurons was scrutinized by G. F. Poggio. It was his conclusion that excitatory and inhibitory functional systems are operationally coextensive at least over the center region of the receptive fields, and that the two mechanisms have similar characteristics with respect to time course of action. During the discussion of this paper De Valois pointed out that, in his view. excitatory and inhibitory influences of opponent colors also extend over the entire receptive field of individual neurons.

In a general discussion of the method of coding of sensory quality in different afferent modalities, R. P. Erickson pointed out the similarities in the translation of colors and of tastes into neural signals. In both cases a limited number of parallel channels coming from a small area of the tongue, or retina, has to perform the discrimination of finely shaded qualitative stimulus differences. If individual color receptors were tuned to a narrow band of wavelengths, the number of available nerve fibers would be insufficient to distinguish all the shades of the visible spectrum (T. Young); hence the broad, overlapping sensitivities of the visual pigments and visual afferents. Similarly, broad tuning occurs in other sensory modalities in which quality is not represented topographically in the nervous system (taste, temperature, and vestibular sensitivity). Topographically organized modalities have sufficient numbers of neurons for each to be narrowly tuned (audition, visual, and somesthetic position).

The leading theme of a paper by I. C. Whitfield was that discrimination of pitch is dependent on the statistical distribution of excitation over a geometrically arranged array of first-order auditory nerve fibers. He pointed out that this is the most feasible system of detection of complex waveforms, such as occur in human speech. Speech sounds are recognized by the relative position of "formants," or dominating frequency bands. Several such bands are presented simultaneously, and recognition is independent of the particular pitch of the speaker's voice. On the basis of observations on the auditory cortex of waking, free moving animals, it was argued that this level is concerned with temporal patterns of stimuli and that responsiveness to a particular frequency is, if anything, more widespread than at lower levels. He claimed that there is no evidence in the normal intact auditory system for the view that specific stimuli eventually activate some unique area or group of cells, but rather that a many-many relationship probably exists between detectors and effectors at several neural levels.

The precise relation between sound waves and discharges of auditory nerve fibers was described by J. E. Hind. For frequencies lower than about 4000 hertz nerve impulses are phase-locked to the stimulating sound waves. Phase-locking occurs in spite of the fact that nerve fibers do not follow vibrations in a one-to-one relationship, even in the lowest audible frequencies. Phase-locking was also seen in Mountcastle's experiments with somatic vibration receptors. Hind also described experiments in which two tones of different frequency and intensity were presented simultaneously. In these cases, phase-locking followed rules reminiscent of psychophysical tonal masking. Hind noted that other studies have shown that the pulse-time coding in the auditory nerve is preserved at least in part at higher levels of the nervous system. The notion that such coding could provide a basis for pitch perception is at variance with that proposed by Whitfield.

The emphasis of the discussion shifted to the anatomical organization of sensory systems. The multiplicity of the sensory receiving areas of the cerebral cortex was discussed by C. N. Woolsey, who reviewed the discoveries of the Wisconsin school over the past two decades. He also presented a new and precise map of the topographical projection of the retina to the first and second visual areas. The question of the source of inputs to visual area I was raised during the discussion. It was the opinion of those speaking that this input originates from subcortical nuclei as well as from visual area II. The need for further study was stressed.

That multiplicity of representation is not synonymous with redundancy of function was emphasized by the presentation of W. D. Neff. He and his collaborators are continuing their effort to define precisely the defects resulting from removal of various parts of the auditory cortex, and surrounding areas. For example, bilateral removal of auditory area I causes a deficiency in ability to locate a source of sound in space without loss of other auditory functions which were tested. Of special interest is the finding that removal of the insulo-temporal areas of cats, sparing auditory areas I and II, caused a permanent loss of the ability to recognize sequential and tonal patterns without a deficit in discrimination of changes in frequency, and also some increase of spontaneous activity in the test situation. To your reporter, this syndrome was reminiscent of the apparent visual agnosia and compulsive exploratory behavior, described by Klüver and Bucy, after temporal lobe ablations in monkeys.

In hedgehogs the total removal of cortical visual area I was followed by severe visual deficit, but only moderate retrograde degeneration in the dorsal lateral geniculate nucleus. By contrast, tree shrews are apparently able to see quite well after complete bilateral removal of their very large striate cortex, even though severe degeneration was found in the lateral geniculate of the operated animals. These findings can be explained, according to I. T. Diamond, by assuming that during the evolution of mammals the ancient tectocortical visual projection was at first invaded by a new geniculo-cortical projection. Later the two systems become progressively separated. The more recent geniculostriate system is organized in a compactly point-to-point pattern of projection. The older connections from midbrain to cortex are diffuse, but not random or haphazard.

R. E. Myers presented anatomical evidence that the monkey's visual cortical mechanism consists of six distinct cortical areas. The striate area, striate-receptive area 19, and area 19 are free of commissural fibers; juxta-striate area 18, area 18 and areas 20 and 21 combined receive commissural fibers throughout. Only the striate area receives heavy projection from the thalamus, primarily from the lateral geniculate, but also from a portion of the pulvinar. Myers described experiments indicating that, in the cat, direct visual sensory input over the primary optic pathways is greatly more potent in memory induction than information indirectly received from the opposite hemisphere through the corpus callosum. Conflicting information fed into a hemisphere through the corpus callosum is incapable of reversing the effects of direct sensory experience.

To sum up, the participants were largely in agreement concerning the nature of coding in receptor organs and the signaling of peripheral sensory nerves. Perhaps a critical voice would have been heard, had we been successful in securing the presence of G. Weddell. Debate was lively with occasional sparks, when the topic shifted to the mechanism of central information processing. Mountcastle stressed the need for adequate identification of the cells that are being observed in experiments using the essentially blind method of probing by microelectrodes. He also pointed out the difficulty of controlling stimulus parameters in free-moving animals. Whitfield reminded us that the dangers of drawing conclusions from the behavior of paralyzed animals may be quite as great as those from anesthetized animals, and that, from higher neural levels, any such results must be viewed with extreme caution.

The meeting was the third annual symposium sponsored by the Research Training Program in Sciences Related to the Nervous System of Duke University.

G. G. SOMJEN
Department of Physiology and Pharmacology, Duke University, Durham, North Carolina

Calendar of Events

Awards

The **Lalor Foundation** program of awards for 1968 emphasizes research in the field of reproductive physiology. The principal present aim of the foundation is to assist qualified investigators working on applied scientific and medical research directed to the study of uterine phenomena relevant to implantation and post-implantation birth control and to better and safer means of female sterilization.

The awards are open to all nationalities. Preference will be given to younger members of university or college faculty and staff with an upper age limit of 41 years. The work may be carried on at the applicant's own institution or elsewhere. The awards may be for a few months or up to 1 year and may range from $1300 to $8500, depending upon the scope and the duration of projects approved.

Requests for information and for application forms should be directed to the Lalor Foundation, 4400 Lancaster Pike, Wilmington, Del. 19805. *Deadline* for executed applications: 15 January 1968.