in the peripheral area in which the pain is localized. The stimulation of these receptors is caused by the reflex responses, probably through the accumulation of waste metabolites or the liberation of a stimulating chemical substance.

The mechanisms involved in the components of the referred pains in question, which are due to reflex phenomena, may be outlined as follows: Impulses arising at the site of a lesion in the nasal or paranasal mucosa are conducted into the spinal cord through afferent components of the upper thoracic nerves, reach the corresponding ganglia of the sympathetic trunks through pre-ganglionic neurons, and are conducted to the periphery through sympathetic neurons. Pain receptors at the periphery are stimulated; the impulses arising in them are conducted into the spinal cord through afferent components of the corresponding spinal nerves and upward through the lateral spinothalamic tract on the contralateral side.

[Author's summary.]

CRITICAL REVIEW

Recent Experimental Work on the Theory of Hearing carried out at the Ferens Institute (described in reprints from the Proceedings of the Royal Society, Series B, No. 827, Vol. 122, pp. 175-85, by C. S. Hallpike, H. Hartridge, and A. F. Rawdon-Smith; and *ibid.*, pp. 186-97, by D. W. Ashcroft, C. S. Hallpike, and A. F. Rawdon-Smith).

The tendency of physiological experimental work is to become more specialized and refined in its methods, and in the elaborate apparatus of which it makes use. No doubt results are being obtained which would have been impossible a few years ago, but the number of those who are capable of following the development of any particular field of research is being progressively restricted to those highly trained in that special branch of science. The theory of hearing is a subject in which aural surgeons can hardly fail to be interested, but it is becoming increasingly difficult for most of them to penetrate the thick-set hedge of technicalities with which modern research surrounds the subject. Any layman who sets out to comment on, elucidate, or criticize recent researches must approach the task with considerable trepidation, as does the present writer.

The publication, in 1930, by Wever and Bray, of their remarkable demonstration of the electrical disturbances evoked by sound stimuli acting on the mammalian cochlea produced a profound impression, and unsettled all existing opinions as to the mechanism

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of hearing. The resonance theory, which had been gradually gaining ground for some years previously, seemed to be discredited. The oscillations of electrical potential were shown to follow in detail every variation in rhythm, frequency, and relative intensity of the sound waves which gave rise to them. A current could be led off which, when passed through a series of amplifiers, to a microphone, or loud speaker, reproduced faithfully the original sounds. Wever and Bray assumed at first that the current which they obtained by placing the active electrode on the stump of the severed auditory nerve represented the current of action in the nerve itself. If this were so, it seemed that we should have to go back again to the "telephone theory" of Rutherford, and even the frequency-intensity mode of transmission of nerve impulses worked out by Adrian, seemed to be impugned. Adrian was the first to draw attention to the fact that these electrical oscillations (the existence of which he confirmed) differed in character from the current of action in a nerve, and that they could be obtained by placing the active electrode anywhere within a fairly wide area around the cochlea, but with greatest advantage in the neighbourhood of the round window. He made the suggestion that they had their origin in the cochlea itself. This view has been supported by a number of subsequent investigations. The next question was in what part of the cochlea did they arise. The most probable site of origin seemed to be the hair cells of Corti's organ, a view which has been supported by Davis and others, in America. In the meantime the Wever and Bray technique has been extensively employed to re-investigate various aspects of the theory of hearing, and the results tend to show that the phenomena to which they called attention are not inconsistent with the resonance theory. This view is considerably strengthened by the two papers which are reviewed here.

As far back as 1921 H. Hartridge devised an ingenious experiment which approximated more nearly to a crucial test of the existence of resonators in the sound perception mechanism than perhaps any other that had been suggested. He used a siren to produce a musical tone, and, by a special arrangement of the apertures in the plate of the siren, he effected an instantaneous change of phase of half a wave-length in the series of waves emitted by it, putting the crests where the hollows had been and *vice versa*. At each change over he was able to observe a short period of silence. His inference was that the pure tone emitted by the siren set up resonant vibrations at the level of the basilar membrane tuned to that frequency. At the change of phase, the existing resonant vibrations had to be damped out, and a fresh series built up. The change over of the basilar membrane to the reversed rhythm occupied an appreciable interval of time, which corresponded to the "period of silence". This could only be explained on the

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supposition that tones on one frequency set up vibrations at a level of the basilar membrane tuned to that frequency, and to no other. Several objections were urged against the methods used in the experiment. The first of the papers under review describes a highly refined modification of the original experiment, designed to eliminate these objections. It consists in recording simultaneously, and on the same film, the electrical variations in the cochlea, tapped by an active electrode placed on the margin of the round window, and the current of action in the auditory tract of the mid-brain, led off through an electrode placed on the lateral fillet. Both currents are amplified before reaching the recording apparatus. It is assumed that the tract response represents the excitations of the auditory nerve by sound waves acting on the sense organ. How and where the cochlear response to the same sounds arises is discussed in the second paper. The source of sound used in the test is identical in principal with that used in the " talking " films of the cinema. A beam of light is thrown on to a copper-oxide photo-electric cell, and the incidence of the light on the cell is rhythmically varied by the passage of a series of equally spaced projections on the rim of a rotating disc. An electric current passing through the cell is varied in strength in exact accordance with the amount of light falling on the cell. If this current is used to activate a microphone or loud speaker, a musical sound is generated whose frequency corresponds to the number of interruptions per second of the beam of light. It is easy to induce a change of phase in this wave-like current passing through the cell, either by interposing a tooth of double width in the series of projections on the disc margin, or by making one gap of double the width of the other spaces. By certain ingenious modifications in matters of detail, the writers succeeded in obtaining from this apparatus a series of beautifully regular harmonic waves, giving rise to a remarkably pure tone. It only remained to record the effect produced by the musical sound, and the phase change on (1) the cochlear response, (2) the nerve-tract current of action. The tracings of the cochlear response were found to follow in exact detail that of the musical sound waves and of the change of phase imposed on them, whilst the tract-response gave an entirely different rendering of the phase change. When a tone of 256 d.v. per sec. was used, the tracing after the change of phase showed a flattening of its contour extending over some seven or eight vibration periods, which corresponds to what Hartridge described in his earlier experiments as a " short period of silence ". The 1024 d.v. per sec. showed a short irregular disturbance following change of phase corresponding to Hartridge's " short noise ", or what has since been called the " phase-change beat ". The inference drawn is that the cochlear response is due to some kind of direct excitation by sounds vibrations acting on some highly damped

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non-resonant structure, e.g. Reissner's membrane, whilst the tract response or nerve current of action set up by excitation of the sense organ (the hair-cells in the organ of Corti), arises from movements set up in the resonant fibres of the basilar membrane. The latter alone shows a phase-change reaction characteristic of a resonance mechanism. Hartridge's original " phase-change experiment " is greatly improved by eliminating mechanical factors in the source of sound and replacing them by physical and electrical methods which reduce the factors of inertia, lag, and distortion to a minimum, and also by producing graphic records, instead of merely observational evidence of the results obtained.

The second paper deals with the question of the site of origin of the cochlear response. The most natural assumption would be that it arises in electrical disturbances set up in the hair-cells of Corti's organ, and this view has been advocated by Davis and others in America. The evidence brought forward by the workers at the Ferens Institute tends to negative this conclusion. They destroyed the auditory nerve in a series of fifteen cats, by pressure of a blunt instrument introduced into the internal auditory meatus. The cochlear response was tested in all the animals at varying periods after their recovery from the operation, and subsequently histological examination was made of the cochleae. It was found that the cochleae were totally degenerated in four of these, no doubt as the result of occlusion of the blood vessels supplying the cochlea. In the remaining animals, varying degrees of degeneration of Corti's organ, and of the spiral ganglion was found, but the activity of the cochlear response by no means corresponded to the amount of damage to the sense organ. In some cases it was wholly or partially lost, whilst little morphological change was found in the sense organ, and in others it was well preserved, or even accentuated, in spite of widespread degeneration in these structures. The only histological change which was found to be constantly associated with diminution of the cochlear response was blocking of the aqueductus cochleae by exudation. This seems to indicate the cochlear fluids as the elements chiefly concerned in the reaction. The writers make the interesting suggestion that the actual site of origin is Reissner's membrane, which they believe to be a " polarized membrane ". Polarization takes place in a membrane separating two fluids of different chemical composition, one of which holds in solution an electrolyte belonging to the class of " electrolytic colloids ". These readily dissociate into a small and a massive ion. The small ions readily pass through a limiting membrane, but are retained in the neighbourhood of the massive ions by mutual electrical attraction. The ions of opposite charge thus become concentrated on opposite sides of the dividing membrane, which is then polarized. Mechanical disturbance of the membrane gives rise to disturbance of the

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potential difference at the two faces of the membrane. As waves of sound in the cochlea have to traverse Reissner's membrane to reach the sense organ, no doubt vibrations in this structure exactly corresponding to the sound waves must occur, and it is to these vibrations that the cochlear response is attributed. This view would seem at first sight to relegate the cochlear response to the position of a merely accidental or adventitious accompaniment of the function of hearing, but it would be difficult to believe that such relatively large electrical variations, which follow so closely all the variations in pressure on the cochlear fluids impressed upon them by waves of sound impinging on the cochlea, can be other than an important factor in sound perception.

G. WILKINSON.

REVIEW OF BOOK

Grundfragen der Phonometrie. By EBERHARD ZWIRNER und KURT ZWIRNER. (Verlag, Metten & Co., Berlin, 1936.)

This book is the first of a series of publications under the general heading of " Phonometrischen Forschungen " which are to appear in two series; (*a*) dealing with the technique of phonometry and the statistical treatment of phonometric data; and (*b*) giving actual phonometric texts.

The task of phonometry is to produce accurate records of speech from which statistics may be prepared. Almost half the book is devoted to an historical survey of phonetics and linguistics from Plato onwards, showing the relationship of linguistics to the physical sciences. Experimental phonetics, the authors contend, has usually overlooked the fact that a speech-sound is a speech-sound *only* in so far as it is used as a means of communication within a linguistic community. Attempts have been made to define speech-sounds by objective means, for instance by reference to their organic formation or by graphical records of their waveforms, but, because *phonetics* overlooked the historical aspect and the functional nature of speech-sounds it could not properly reconcile itself to the differences between the variable norms of pronounciation, and the actual sounds used by individuals in speaking. Finally, the method of making phonometric texts from gramophone records is described. Such texts, unlike phonetic texts, show *not a kind of norm* of the pronunciation used by a large linguistic community, but are records of the speech of one particular person on one particular occasion.

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