Electrical Stimulation of Eighth Cranial Nerve

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This is a report concerning the methods by which we have succeeded in stimulating the eighth nerve electrically. To carry out this study certain postulates were made for the purpose of selecting the initial experiment.

We first assumed that many patients suffering from congenital and acquired hearing loss harbored a defective or inadequate organ of Corti rather than a functionless auditory nerve.[1] It would follow therefore that we should attempt to develop a method of stimulating the nerve electrically, in a manner similar to that previously done by Djourno et al.[2]

An additional postulate was that the individual nerve fibers of the auditory branch of the eighth nerve are nonspecific.

We further assumed that the number of nerve fibers firing simultaneously is a function of the instantaneous sound intensity, that the number of serial firings per second is a function of frequency, and that interpretation of this information is effected by means of temporal summation in the brain.

These assumptions are in contradiction to conclusions that have been arrived at by others as to the specific nature of nerve fibers as related to their position in the cochlea.

Experimental Method

The initial studies were carried out on patients suffering from acquired and congenital deafness. Initially the tympanic membrane was turned down and electrodes placed on or near the oval and round windows. Subsequently the active electrode was passed through an anesthetized eardrum. In these cases the ground electrode was attached to a speculum inserted in the external canal.

The first experiment was to apply a square wave of 400 cycles to the eighth nerve (Fig 1). A tone was perceived at a level of approximately 0.5 v. As the voltage was increased slightly above the threshold of hearing, the tone abruptly reached the threshold of pain. In the majority of cases so studied, vertigo and nystagmus did not occur unless there was a considerable increase in amplitude and frequency of the square wave above thresholds.

By varying the frequency of the square wave, the majority of patients were able to discriminate between higher and lower tones which roughly approximated the rate of the square waves. When the frequency exceeded 1,000 cps, the tone was lost and the patients perceived sound described as noise.

It is probable that the variations in the absolute refractory time of the individual nerve fibers may produce noise. When the stimulus exceeds the

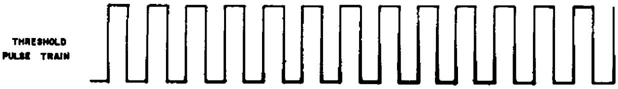

Fig 1.—A 400 cycle threshold square wave.

Read before the Committee for Research in Otolaryngology, American Academy of Ophthalmology and Otolaryngology, at the Seventh Annual Meeting, New York, Oct 19, 1963.

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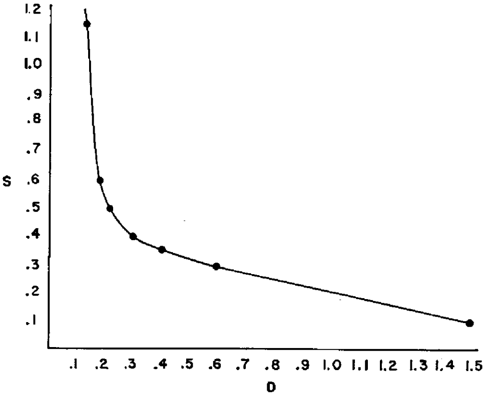

Fig 2.—Strength-duration curve of the eighth nerve of a patient with acquired total deafness.

absolute refractory time, it is obvious that the nerve fibers can no longer fire in unison or synchrony with the stimulus.

During the testing of each patient, strength-duration characteristics were measured and were found to correspond closely to the normal characteristics of other peripheral nerves (Fig 2). No essential difference was noted in the curves obtained from patients with so-called nerve deafness, either the congenital or acquired type. Four of the 14 patients studied had no recollection of prior hearing. They expressed delight in experiencing a musical tone.

In order to introduce stimuli which might be interpreted as additional information over and above a simple tone, complex stimuli were created. A pulse train of square waves of threshold intensity upon which was superimposed a sine wave of variable frequency was applied to the nerve (Fig 3). The composite signal was interpreted as two separate tones. As the frequency of the sine wave approaches that of the basic pulse train, the second tone was lost (Fig 4).

When the frequency exceeded the basic rate of the pulse train, a second tone was again perceived by the patient and was essentially identical to that experienced when the sine wave was slower than the train of square wave pulses. This recurring second tone was audible when its frequency was not that of a multiple of the threshold pulse train. Therefore, sine waves of increasing frequency were heard by the patients as recurring low tones not exceeding the maximal rate of the pulse train.

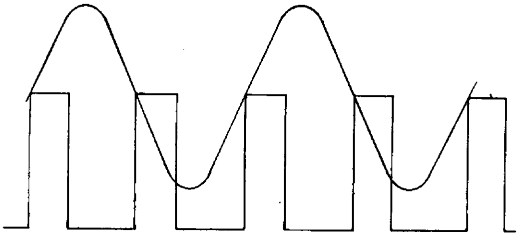

Fig 4.—Loss of modulation effect with integral frequencies.

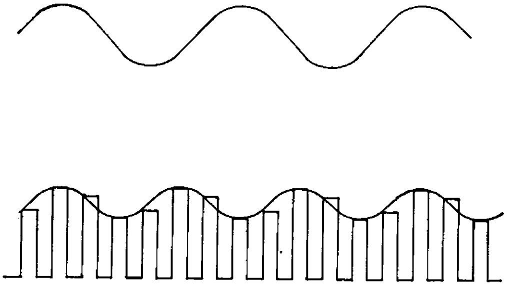

Fig 3.—Amplitude modulated square wave.

Subsequently, speech signals were superimposed upon a threshold pulse train of square waves. These signals enabled the patients to perceive the rhythm of speech and music, to differentiate high from low tones, and to distinguish an occasional word. Lip reading was facilitated by the use of these stimuli.

A final experiment was made by placing the electrode in the cochlea instead of in the middle ear. It was found that the range of intensity from the threshold of audibility to the threshold of pain was substantially less than when the electrode was in the middle ear.

In November of 1962, an induction coil which had been previously imbedded in methyl methacrylate was inserted in a craniotomy defect in the squamous portion of the temporal bone of a patient suffering from essentially total congenital perceptive hearing loss. The active electrode was passed through a bony tunnel into the middle ear and through a fenestra in the promontory of the cochlea between the oval and round windows. The ground electrode

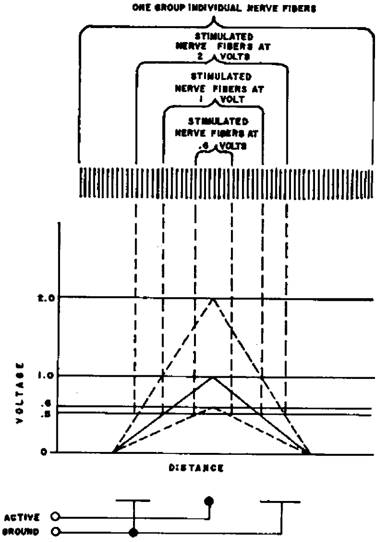

Fig 5.—Electrical field produced by gradient probe.

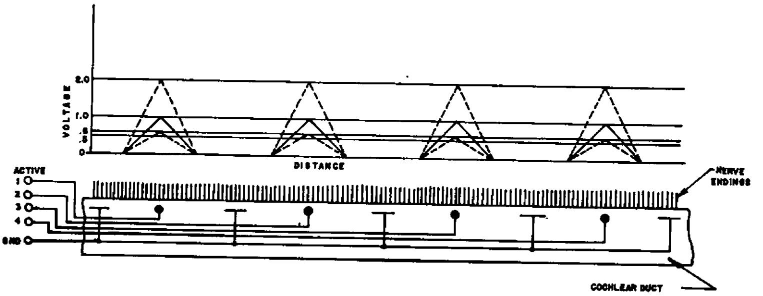

Fig 6.—Fild distribution along cochlea with four-channel gradient probe.

was placed beneath the temporal muscle covering the induction coil implant.

The induction coil was energized by an external coil worn by the patient in a manner similar to an earphone head set. A transistorized portable energy source powered the external coil. In this way, signals picked up by a microphone could be superimposed on the threshold square wave.

To date the patient has been able to perceive the rhythm of music and speech and can differentiate between male and female voices. She is currently trying to associate sounds with lip reading. It appears that her ability to speak may be improving.

This single-channel unit can only provide a limited amount of information because of its narrow dynamic range and because of the maximal rate at which the individual nerve fibers can be fired. The theoretical band-width of this unit is approximately 200 cps.

The limitations found in the initial stage led us to return to the original postulates in an effort to design a system which would extend the dynamic range in a controllable manner.

To provide good voice communication with the patient, it is necessary to increase the band-width of a system above the natural limit imposed by the refractory period of the individual nerve fibers.

In accordance with our original postulate that the intensity of the perception of sound is related to the number of nerve fibers firing simultaneously, it became necessary to develop a means by which the amplitude of a pulse would bear a fixed relationship to the number of nerve fibers stimulated.

Fig 5 shows the mechanical construction of a gradient probe and the electrical field that is produced at the nerve endings when the probe extends along a section of the cochlea.

At the top of the figure, the nerve endings are schematically shown. The graph below the nerve endings represents the electrical potential applied to the nerves when pulses of three different amplitudes are applied to the active electrode.

If one makes the assumption that the nerve fibers will fire when they are stimulated with a potential greater than 0.5 v, then, as shown in the figure, if 0.6 v is applied to the active electrode, the central portion of the nerve fibers will be stimulated. If the pulse is increased to 1.0 v, a larger number in the central area will be stimulated, and correspondingly for 2.0 v. Coincidentally, the ground electrodes both isolate and shield the field from reaching other nerve endings.

The second limiting factor in these studies appeared to be the absolute refractory period of the eighth nerve. It was postulated that stimulating several portions of the nerve independently might increase the band-width and enable the patient to obtain useful speech perception.

Four separate gradient probe electrodes were introduced in four different locations in the cochlea of a patient with acquired perceptive deafness (Fig 6).

These electrodes were stimulated sequentially with threshold square waves upon which were superimposed speech signals. In this manner it was possible to introduce electrical signals at 600 cps in four areas of the nerve which when temporally

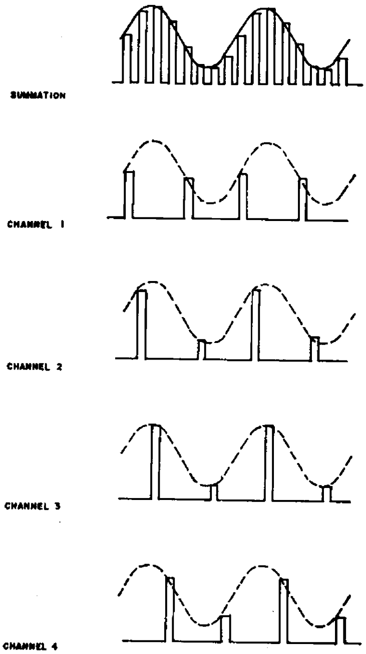

Fig 7.—Summation effect with four-channel stimulation.

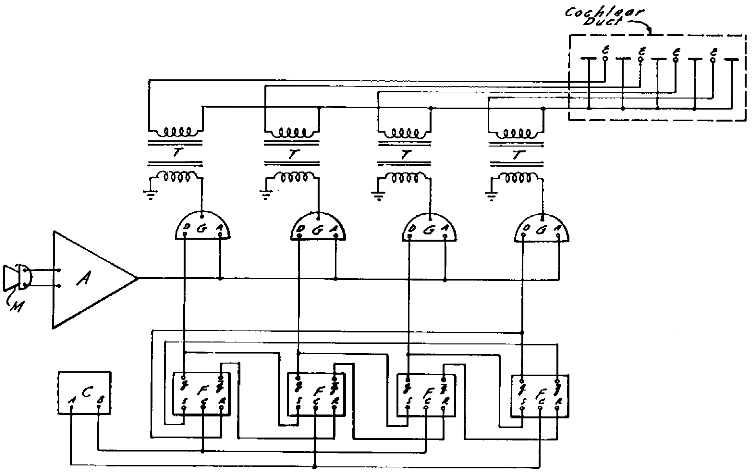

Fig 8.—Block diagram of four-channel system. Four *F* blocks in combination with *C* produce four square waves time displaced. The combination (*M*) microphone, (*A*) amplifier, a four (*G*) gate modulator superimposes the audio signal on the square waves. Four transformers (*T*) with external primaries and internal secondaries transfer electrical signals to the multichannel gradient probe in the cochlear duct.

summated would arrive at higher auditory centers at the rate of 2,400 cps, as shown in Fig 7. Definite speech perception attained by such complex stimuli enabled the patient to repeat phrases. The electrical circuit necessary to accomplish this is shown in block diagram in Fig 8.

This four-channel unit has a theoretical bandwidth of 800 cps. Because of the gradient probe it has a broad dynamic range.

A subsequent experiment was performed in order to test the validity of our postulate on the nonspecific nature of the individual nerve fibers. The four active electrodes were stimulated one at a time, and the patient could not distinguish one stimulus from the others. This experiment confirmed our postulate as to the nonspecific nature of the nerve fibers.

We now believe that a 16-channel unit will be required in order to pass audio signals similar to telephone transmission.

It is our hope that this work will stimulate increasing cooperation between the disciplines of medicine and physics in the hope of achieving solutions to intricate and significant problems.

Recent advances in the field of electronics brought about by the space program have made available miniature components of unusually high reliability. It remains for those in the medical profession to approach those in the field of physics and to inform them of their medical needs in order that new tools and methods may find their place in the practice of medicine.

Summary

A method of stimulating the eighth cranial nerve electrically is described, and the postulates formulated as a basis for such experiments are given. Experiences gained from introducing simple and complex electrical impulses are described with their practical application in totally deaf patients.

The Hollywood Presbyterian Hospital, Olmstead Memorial, Department of Eye, Ear, Nose & Throat, Los Angeles contributed to and cooperated in this work.

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