EFFECTS OF MECHANICAL STIMULATION ON THE NERVE FIBER

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A considerable amount of research has been reported on the effects of mechanical stimulation to mechanoreceptors. However, because of the difficulty of stimulating the node or the internodal part of nerve fiber, the literature dealing with the analysis of the mechanisms of mechanical stimulation of the nerve fiber is few.

The purpose of the present paper is to elucidate the effects of mechanical stimulation and to analyse their excitation mechanisms.

METHOD

The technique used was essentially the same as that described by Kato (1934) and Tasaki (1953). Experiments were made on isolated single myelinated nerve fibers of the toad, and the bridge insulation method described by Tasaki (1953) was used to lead and record the action current. In Fig. 1, N1 and N2 indicate the nodes of Ranvier immersed in Ringer's solution. A and B are the glass plates separated by an air gap, across which the myelin portion of a single nerve fiber was mounted.

Electrical stimulation was given to the nerve trunk through the electrodes E in Fig. 1 which were separated from each other by an electrical insulator wall. The mechanical transducer of electrical pulse consisted of a moving coil of electrodynamic speaker and an electrically insulated bar. Electric square pulses of short duration were given through a power amplifier to the moving coil. The strengths of the mechanical stimulation were measured as the intensities of the piezoelectric potentials as shown in Fig. 2. In Fig. 3 the piezoelectric potentials (P) and the time delays (T) are plotted as ordinates against the pulse voltages added on the power amplifier as abscissae. This figure indicates that the linear relation exists between the piezo-
FIG. 2. Intensity and response time variations of piezoelectric potentials, produced by electrical square pulses lasting 3 msec. Intensity of pulses progressively increased from B to H.

Fig. 3. Relations of piezoelectric potentials (P) and time lags of response (T) to strengths of square pulses.
electric and the pulse potentials. These mechanical stimulations of varying strengths were given to the nerve trunk, and time delays of the stimuli were measured on Fig. 3. The real response time to a stimulus was given by reducing this time delay from the obtained result.

RESULTS

I. Responses to mechanical stimulation.

The effects of mechanical stimuli on the nerve trunk are illustrated in Fig. 4. In this figure, Record A was obtained by an electrical stimulus as the control. By a subthreshold mechanical stimulation was obtained Record B, in which visible damped vibrations followed the mechanical shock artefact. Record C shows the response to the weakest effective mechanical stimulus. The action
current was seen after the damped oscillation of shock artefact; however the excitation of the nerve fiber should be considered to have been caused by the mechanical stimulus and not by the damped oscillation. In the case of a single strong mechanical stimulation of the nerve trunk, repetitive excitations were induced in the single nerve fiber as shown in records D and E. When mechanical stimuli were applied directly to the isolated part of single nerve fiber, stronger stimulations induced decrease in excitability, by the extension of the nerve fiber due to the vibration of the stimulating apparatus.

II. Relationship between the response times and the mechanical and electrical stimulations.

This section describes the experiments observing the difference of response time between mechanical and electrical stimulations. Fig. 5 shows one of the results obtained. The records in Series A show the case of the electrical pulse (0.2 msec) and those in Series C the case of electrical stimulation of longer duration and near rheobasic intensity. The action currents of Series B were induced by mechanical stimulations. The relations between the response time and stimulus strength in these records are illustrated in Fig. 6. Curve A, B and C refer to the series of the same name in Fig. 5. The stimulus strengths were

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**Fig. 5.** Responses to electrical stimuli of short (A) and long (C) durations and to mechanical stimuli (B). Numerals on both sides indicate electrical voltages in reference to column A and C respectively.
FIG. 6. Diagrammatic representation of response times in relation to stimulus strength. Curves A, B and C refer to the columns of the same designation in Fig. 5.

represented as percentages of the threshold intensity. In these results, the response times were about 3 msec including the conduction time from the stimulated point to the node N1, and in the case of mechanical stimulation the response times were always smaller than those of the rheobasic electrical stimulation. When a stronger stimulation (140% of threshold) was used, the difference of the response times was only 0.6 msec.

III. Effects of mechanical pressure on the excitability of the nerve.

The effects of mechanical pressure applied to the nerve trunk were examined by measuring the strength-duration relations under varying conditions. The pressure was given by the same apparatus as described by Loewenstein and Rathkampf (1956). Strengths of the pressure could not be measured. The experimental procedures are schematized in the inset of Fig. 7. The pressure and the catelectrotonus were given on the nerve trunk as conditioning alterations. An example of the results is presented in this figure, which shows a strength-

FIG. 7. The Strength-duration curves. Pressure and catelectrotonus (C.E.T.) were given to the nerve trunk as conditioning (see inset).
duration curve under mechanical conditioning (dotted line) and similar curves measured under the normal and catelectrotonic conditions of varying intensity. In the case of the mechanical pressure the threshold and the rheobase decreased by 23% and 11% respectively of the normal values. This increase in the excitability of the nerve was equal to that seen in the catelectrotonus of 20-40 mV.

**FIG. 8.** Diagram to illustrate the increased excitability in the neighborhood of the portion mechanically stimulated (FIG. 1 M) with a brief subthreshold conditioning shock. Ordinates show the thresholds of the test shock in percentage of that without conditioning shock. Abscissae indicate the intervals of the conditioning and test shocks in msec.

**FIG. 8** is a diagram to illustrate the transiently increased excitability existing in the neighborhood of the portion mechanically conditioned with a brief (3 msec) shock of subthreshold intensity. As the test shock an electrical pulse of 0.2 msec duration was used as described by Katz (1939). The required sizes of test shocks to bring excitation to threshold level after the conditioning shocks, were determined at various intervals, and plotted as ordinates in percentages of the normal threshold. According to this result 11% decrease of threshold of the test shocks was shown at the interval ranges from 12.4 to 4.5 msec, and the decreases of the thresholds were 21% and 31% for the intervals of 1.0 and 0.1 msec respectively.

**DISCUSSION**

Our observations clearly demonstrate that the nerve fiber responds to direct mechanical stimulations with a single discharge or with train of discharges according to the strength of stimulation. From the relationship between the strength and duration of the test square pulses, the increase in excitability was also evidenced as indicated in Fig. 7. The effect of the pressure here employed on the nerve matched the action of catelectrotonus of 20-40 mV. It was also made clear that this increase of excitability lasts about 15 msec as represented in Fig. 8, even if it is produced by a single subthreshold mechanical shock of short
duration. Therefore, a possibility exists that with stronger stimuli, the excitation by mechanical stimulation may last much longer. Because of this prolonged increase in the excitability, it is not surprising that the repetitive excitations were produced as shown in Fig. 4 by a single mechanical shock.

The following concept has been put forward by Hayashi (1956): Flowing out of electric current at the node of Ranvier brings some changes which release some chemical substance; the excitation by mechanical stimulation might be produced by separation of a certain chemical substance, Excitin. It was suggested by him that the latency would be longer in the case of mechanical stimulation than in the case of electrical stimulation, due to the long liberation time of the chemical substance. In our results, however, no remarkable difference of the latency was found between mechanical and electrical stimulations, the former giving always an intermediate value between those of short electrical pulses and the rheobasic stimulating currents.

SUMMARY
1. The effects of the mechanical stimulations on the nerve trunk were examined by recording propagated action currents from a single nerve fiber.
2. In the case of single brief mechanical shocks, the nerve fiber responded to them in the ratio of 1:1. A single strong shock produced invariably, repetitive excitation.
3. The response time of the mechanical stimulation was found to lie between those of short electrical pulse and of rheobasic stimulating current.
4. The effect of mechanical pressure on the nerve fiber was identified with the action of catelectrotonus. The pressure on the nerve fiber produced an increase in excitability, and the increased excitability in the portion stimulated with a brief mechanical subthreshold shock lasted about 15 msec.

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REFERENCES
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