The Cover of the JJP (Vol.1(1)) and Its Contents

JJP 第１巻第１号　表紙と目次

THE

JAPANESE JOURNAL

OF

PHYSIOLOGY

EDITED FOR

THE PHYSIOLOGICAL SOCIETY OF JAPAN

BY

YAS KUNO

Volume 1

June 1950 - March 1951

THE JAPANESE JOURNAL

OF PHYSIOLOGY

VOLUME 1

JUNE 1950-MARCH 1951

CONTENTS

TASAKI I. (Jpn J Physiol. Vol 1 : p.1-6, 1950)

ELECTRICAL EXCITATION OF THE NERVE FIBER
PART I. EXCITATION BY LINEARLY INCREASING CURRENTS

ICHIJI TASAKI[1]

Physiological Institute, Keio University, Yotsuya, Tokyo

Since Keith Lucas (3) reported his classical experiments, there has been a considerable amount of work dealing with the problem of excitation of nerve or muscle by linearly increasing currents (Fabre (2), Blair (1), Sugi (4) and others). The experimental results obtained with artificially isolated single nerve fibers, which are presented in this paper, seem much simpler and more decisive than the previous results obtained with nerve trunks.

METHOD

Toad's large motor nerve fibers were used for the experiments. The internodal stretch of the nerve fiber was laid on a "bridge-insulator" (5), and non-polarizable electrodes were immersed in the pools of Ringer's fluid on both sides of the bridge-insulator (Fig. 1). For stimulation of the fiber, the circuit shown in the figure was used. Two break contacts of a Helmholtz pendulum (K_1 and K_2) were opened in succession; charging of the condenser C (20 μF.) was started by opening the first contact K_1 and the discharge was begun by breaking the contact K_2. As the electrical resistance of the preparation on the bridge-insulator was sufficiently great (being several ten megohms), the RC product in charging the condenser could be regarded as being 1 sec. The resistance of the

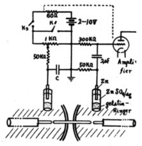

Fig. 1. Experimental arrangements used for stimulating single nerve fibers.

[1] 田崎一二

This paper except for its appendix was received for publication February 22, 1944 by the redactor of the Japanese Journal of Medical Sciences (Biophysics).

contacts of the pendulum was less than 0.1 ohm.

With this stimulating circuit, the temporal configuration of the potential difference applied to the nerve fiber can be given by the formula

$$V(t) = V_i(1 - e^{-t/RC}),$$

where V_i represents the voltage given by the potential divider. If the time under consideration is far smaller than RC (= 1 sec.), the voltage can be regarded as increasing linearly: namely,

$$V(t) = V_i t/RC.$$

Electrical responses of the nerve fiber was observed by means of a Braun tube. The action current was amplified with a four-stage resistance-capacity coupled amplifier. Figures on the screen of the Braun tube was photographed with a Leica camera.

RESULTS

(1) *The relation between the latent period and the voltage-gradient.* The time-interval from the start of a linearly increasing current to the appearance of the action current at the site of stimulation is here designated as the latent period. When the rate of increase of the stimulating voltage was varied by changing the final voltage V_i in the above-stated formula, the latent period was found to vary inversely as the gradient of the voltage.

Fig. 2 gives an example of the experimental results obtained. In this figure, the straight lines represent the temporal configuration of the voltage applied to

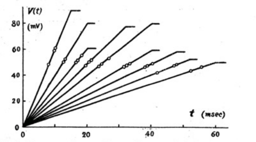

Fig. 2. Relation between voltage-gradient and latent period of action current. The circles indicate the moment at which the action currents appeared at the site of stimulation when the nerve fiber was excited by the voltages represented by the straight lines. 12° C.

the nerve fiber: they rise linearly, until they abruptly change into horizontal lines corresponding to the slow decline of the voltage following the break of the second contact in the stimulating circuit. The circles in the figure indicate the moments at which the electrical responses of the fiber appeared.

As has been well-known, stimulating voltages with small gradients failed to elicit electrical response in the nerve fiber. For the gradients greater than a certain critical value, electrical responses were found to appear when the voltage

reached an approximately constant value which was approximately equal to (or slightly greater than) the rheobasic voltage of the fiber. The minimal gradient of the stimulating voltage, at which the stimulus could barely excite the fiber, was in some fiber greater than 1 mV/msec., and in others less than 0.2 mV/msec.

(2) *The relation between the liminal voltage and the voltage-gradient.* The stimulating voltage obtainable by the use of the stimulating circuit shown in Fig. 1 shows a configuration as given in Fig. 3, top. The time of voltage-increase d could be varied by changing the distance between the two contacts K_1 and K_2. The final plateau value v of the voltage could be controled by changing the final voltage V_i.

In this series of experiments, the value of v (consequently the voltage-gradient) was changed at each fixed value of d, and the liminal value of v, which just excited the fiber, was measured. The rheobasic voltage, corresponding to the liminal voltage v for $d = 0$, was first determined by disconnecting the condenser and short-circuiting the resistance (50 KΩ). In the determination of the liminal v value for $d = 10$ msec., a condenser of the capacity of 4 μF. was used.

The observation was begun with stimulating voltages of well above threshold. As the final value of the voltage was decreased step by step at a given time of ascent d, the latent period of the action current was lengthened correspondingly. And, when the latent period reached the time of ascent d at that condition, the latent period showed a marked variation. When the final voltage

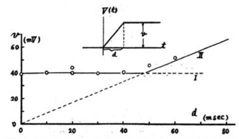

Fig. 3. Relation between time of voltage-increase d and liminal voltage v in a motor nerve fiber of the toad. 17° C.

was still decreased, the action current of the fiber was found to disappear.

Fig. 3 gives a typical example of the results obtained. The liminal voltage v showed a striking constancy for a wide range of the time of ascent d. When the voltage gradient approached the minimal gradient of that fiber, the liminal voltage showed an increase, indicating a gradual transition from the straight line I in the figure to the straight line II.

DISCUSSION

The experimental results described above seem to be nothing new. In the

results obtained by Keith Lucas (3) for the toad's muscle, we find a few figures resembling those shown above. With the experimental arrangements adopted by Sugi (4), the minimal gradient of the muscle appeared to show a very small value, and the rise of the final voltage corresponding to the straight line II stated above was not observed. In the experiments in which nerve trunks were used, the deformation of the stimulating current by the surrounding inactive tissues and the difference in the minimal gradient in the constituent nerve fibers seem to complicate the experimental results obtained.

The result of the experiment of Fig. 3 shows us very clearly that a linearly increasing voltage excites a single nerve fiber when it rises above the rheobasic voltage at a gradient greater than the "minimal gradient" of the fiber. It will be shown in the subsequent papers that this conclusion is of great significane in dealing with threshold conditions in excitation of single nerve fibers with slowly increasing voltages.

SUMMARY

Isolated single nerve fibers of the toad were excited by voltages increasing linearly at varying rates. It was concluded that a linearly increasing voltage is effective in evoking an electrical response in the fiber when it rises above the rheobasic voltage at a rate greater than the minimal gradient of the fiber. Electrical responses are evoked at short (and somewhat variable) time-intervals after the stimulating voltages have reached the rheobasic voltage.

LITERATURE

1. BLAIR, H. A. *J. Gen. Physiol.* 15: 731, 1932.
2. FABRE, P. *C. R. Acad. Sci. Paris.* 184: 699, 1486, 1927.
3. LUCAS, KEITH. *J. Physiol.* 36: 251, 1907.
4. SUGI, S. *Nihon Seiri Z.* (Japanese) 4: 95, 1939.
5. TASAKI, I. *Amer. J. Physiol.* 125: 367, 1939.

APPENDIX

(received for publication March 30, 1950)

Although six years have passed since the manuscript of this paper was first submitted to the editorial board of the Japanese Journal of Medical Science, it seems to me still worthy of publishing this manuscript in its original form. I add to this paper, on this occasion, oscillograms which support the conclusions stated in the paper.

Fig. 4 shows the experimental arrangements used for taking the pictures furnished in Figs. 5 and 6. Linearly rising voltages were obtained by charging a condenser through a high mutual conductance pentode (6302). The stimulus was started by means of a gas discharge tube (thyratron) of which the grid was connected to the sweep circuit. The voltage generated by the sweep circuit was such that the deflection (X) plate of the Braun tube was, first strongly negative and then turned positive. To block the current between the sweep

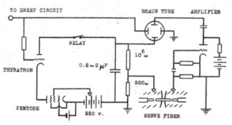

Fig. 4. Arrangements used in the experiments of Figs. 5 and 6.

circuit and the grid of the thyratron, a rectifier (selenium) was connected between the two.

The linearly rising voltage thus obtained was led to one of the deflection plates of the Braun tube, and the voltage was tapped so as to apply to the nerve fiber. The action currents of the fiber was amplified with a 4-stage amplifier (simplified in the diagram) and was led to the other Y-plate. The input resistance of the amplifier was approximately 0.1 megohm. The degree of amplification was reduced to such an extent that the electrical responses of the fiber were just perceptible on the screen of the Braun tube. As insulation of the preparation with the bridge-insulator was perfect, the stimulating current flowing through the nerve fiber introduced no appreciable disturbance into the records obtained.

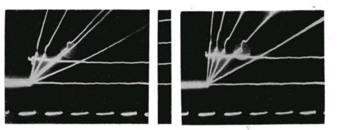

Fig. 5. Oscillograph records of the linearly rising voltages, obtained by means of the electrical circuit shown in Fig. 4, with marks of the action currents on their courses. Right and left, taken from two different preparations at 11° C. The bars in the middle show the deflection of the electron beam by constant voltages of 0, 50, 100 and 150 volts. Time mark, interrupted at 50 cycles per sec.

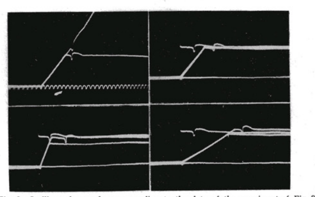

Fig. 6. Oscillograph records corresponding to the data of the experiment of Fig. 3. The linearly rising voltages were made to change into slowly declining (almost constant) voltages by opening the charging circuit by means of a relay operated by another thyratron tube. Constant voltages of the rheobasic strength were also photographed on the films. 11° C. Time, msec.