THE INTERACTION IN VARIOUS MANIFESTATIONS (OBSERVATIONS ON LILLIE'S NERVE MODEL) PART I. THE ACCELERATING ACTION

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Some studies were made previously (Yamagiwa (1)) on the interaction between two Lillie's nerve models lying in parallel and close to each other. The chief results obtained were the following three:

- 1) The synchronization of two waves, when two cores of different conduction velocities are activated simultaneously.
- 2) The "slowing" of the velocities of two cores of one and the same or nearly the same conduction velocities, when the cores are activated simultaneously.
- 3) The acceleration of an activation wave in one core after a sweep of an activation wave in the other core.

Further studies have been made on the accelerating action and also on a few other aspects of interaction, in the hope of throwing some light, if possible, on the same or similar problem in nerve physiology, where the interaction among fibres or ganglion cells turned out to be of fundamental importance in recent years. Here, some detailed examinations made on the accelerating action will be described.

The apparatus, the general method and the experimental conditions are almost the same as those in the former experiment. It will be just mentioned here that in a columnar groove, which was 47 cm., 2.5 cm. and 1 cm. in length, breadth and depth respectively and filled with strong nitric acid (1.35 in specific gravity), two or more models were laid in parallel, to be stimulated with a small piece of zinc foil. As to the details, the readers are asked to refer to the previous paper (Yamagiwa (1)).

THE NUMBER OF CORES CO-EXISTING

1. *The influence of multiple cores activated simultaneously.*

One long core (35 cm. in length) and eight short cores (17.5 cm. long) were arranged as shown in the diagram (Fig. 1).

Fig. 1

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The short cores were very close to each other (2-3 mm.) and all connected together, leaving the long one alone, by means of Hg outside the fluid, so we could activate them simultaneously by stimulating just one of them, namely, by applying the stimulus R_B or R_C to the right or left end of one of the short cores.

First, a stimulus, R_A , was given to the right end of the long core, and the conduction time was measured for both halves AB and BC by means of two stop-watches held in both hands. (In this case, the short cores were of course not activated.) Then the same was done after an extra-stimulus R_C or R_B which was given exactly 5" previous to the application of the stimulus R_A . The ratio $(\text{Cond. Time})_{BC}/(\text{Cond. Time})_{AB}$ was made for both cases, to be compared with each other. The results are given in Table 1 and illustrated in Fig. 2. Of course all the measurements were performed at a certain definite immersion time. It was 5 min. in the experiment for Table 1.

Table 1

Time	Stim.	(C.T.) _{AB} in 1"/5	(C.T.) _{BC} in 1"/5	Mean of (C.T.) _{BC} /(C.T.) _{AB}	Remark
1h. 20' ¹⁾ 30' ²⁾	— R_A and R_C	— —	— —	— —	¹⁾ The cores were set. ²⁾ Stim. for smoothing.
35' 40'	R_A (alone)	4 4	5 5	1.2	
45' 50' 55'	R_A (with R_C)	5 4 4	3 3 3	0.7	
2h. 60' 5'	R_A (alone)	6 6	8 7	1.2	
10' 15' 20' 25'	R_A (with R_B)	6 6 ³⁾ 6	3 3 4	0.6	³⁾ Failure
30' 35'	R_A (alone)	8 7	10 9	1.3	
40' 45'	R_A (with R_C)	7 7	4 4	0.6	
50' 55'	R_A (alone)	9 8	9 10	1.2	
3h. 60' 5' 10'	R_A (with R_B)	7 — ⁴⁾ 7	5 — 5	0.7	⁴⁾ Failure

The measurements were not very accurate, and the $(\text{Cond. Time})_{AB}$ itself was not constant, either, but still it is unmistakably clear and definite that the ratio $(\text{Cond. Time})_{BC}/(\text{Cond. Time})_{AB}$ appears small if measured directly after an extra-stimulus R_B or R_C . This is nothing but a reascertainment of the previous finding (Yamagiwa (1)), by means of multiple cores co-activated, instead of one.

Fig. 2

After having thus ascertained a large accelerating effect of multiple cores upon a certain definite core, we proceeded to examine the effect in relation to the number of the cores co-activated. It was performed just in the same way as in above, except that we varied the number of the short cores. All the results obtained agreed well in the general tendency. We are going to give here, omitting the details, just an example of those in an illustration (Fig. 3).

Fig. 3

There in Fig. 3, it is shown that the $(C.T.)_{BC}$ gets smaller with larger number of the short cores. Generally speaking, the accelerating action in question increases with increasing number of the cores co-activated.

2. *The influence of core I (activated) on core II (resting), in presence and absence of other cores.*

Three or four cores were brought under examination (Fig. 4).

Fig. 4

The cores I and II were made from one and the same sample under similar and careful manipulations, which made their conduction velocities practically equal when examined separately.

The stimulus was applied to a point near one end of the core, to measure the conduction time for the whole length. The measurement was done for the

core I to begin with, and then, directly after that, for the core II, in presence and absence of other cores. Taking the $(C.T.)_I$ as standard, the ratio $(C.T.)_{II}/(C.T.)_I$ was made for both cases and compared with each other, in order to detect the influence of the existence of the cores III and IV upon the shortening effect of the core I upon the $(Cond. Time)_{II}$. The immersion time chosen was 3-5 min. The Table 2 will serve as an example of the data obtained.

Table 2

Cores in use	Time	$(C.T.)_I$ in 1''/5	$(C.T.)_{II}$ in 1''/5	Mean of $\frac{(C.T.)_{II}}{(C.T.)_I} \times 100$	Remark
I	9h. 42' ¹⁾ 51' ²⁾ 56'	— — 7 ³⁾	— — —	— — —	¹⁾ Moment of immersion. ²⁾ Stim. for smoothing. ³⁾ $(C.T.)_I$ proper.
I, II	10h. 1' 6' 11' 16'	(3) ⁵⁾ 7 7 7	7 ⁴⁾ 3 3 4	48	⁴⁾ $(C.T.)_{II}$ proper. ⁵⁾ Trial measurement of $(C.T.)_I$ after that of $(C.T.)_{II}$.
I, II, III	21' 26' 31'	7 7 7	4 4 4	57	
I, II, III, IV	36' 41' 46'	7 8 7.5	5 5 5	62	
I, II, III	51' 56' 11h. 1'	6 7 7	4 4 4	60	
I, II	6' 11' 16'	6.5 7 6.5	4 4 3	55	

Fig. 5 is the illustration of Table 2 and of other two similar series of observations, the numerical data being omitted.

It is clear from the above data and illustration, that the co-existence of other cores weakens the accelerating effect of the core I on the core II, very probably

Fig. 5

because the cores are making the field resistance smaller and the current flowing into the core II the weaker.

Remark. In both cases 1 and 2, above mentioned, the influence in question would perhaps have appeared much stronger if a number of cores could have been arranged *around* a certain definite core, instead of being laid horizontally. In horizontal arrangement, the distant cores can exert only weak influences, both as accelerators and as suppressors as well.

THE DISTANCE BETWEEN THE CORES

It is naturally expected, from theoretical as well as empirical stand-points of view, that the accelerating action of an activated core upon a neighbour will get decreased with increased distance between them. To examine how it is, two cores, I and II, were taken up, both being made from one and the same material and, consequently, of practically the same conduction velocity. They were laid in parallel, several millimeters apart from each other.

At a certain definite immersion time, the conduction time of the core I was measured first, and directly after that (in less than 3" usually), the core II was activated to compare its conduction time with that of the core I. The distances chosen were 2 mm., 4 mm., 8 mm. and 16 mm.

To spare the space, the numerical details will be omitted, and only the final results will be given in a simplified table (Table 3) with its illustration (Fig. 6). We see there a clear increase of $(\text{Cond. Time})_{\text{II}}$ as the sequence of the increase of the distance, that is, a clear tendency of the accelerating action to decrease with increasing distance between the cores.

Table 3

Distance	$\frac{(\text{Conduction Time})_{\text{II}}}{(\text{Conduction Time})_{\text{I}}} \times 100$			Mean
	Experiment I	Experiment II	Experiment III	
2 mm.	50	40	53	44
4 mm.	65	55	82	67
8 mm.	69	89	83	80
16 mm.	100	82	86	89

Fig. 6

THE DIRECTION OF THE ACTIVATION WAVE AS THE ACCELERATING AGENT

In all experiments hitherto performed, the stimuli were always given to the right or left ends of the cores, in other words, the waves in the cores under examination were all running in the same direction. What will then the matter be, if they are made to run in opposite direction?

Employing two cores, the observations were made on this point repeatedly, but we could not find any difference. Of course the velocity was not always invariable but fluctuated temporally in a certain range as in other experiments. But the fluctuation was quite independent of the change of the wave direction, and we came at length to the conclusion that the direction of the activation wave is not significant for the manifestation of the accelerating action.

We recollect here the well-known fact that the reflex time for the so-called "Eigenreflex" is extraordinarily short, sometimes too short to be consistent with other knowledges on nerve. Might it not be, in part, related to the phenomenon here observed in the model? The afferent proprioceptive impulses coming up from a stretched muscle might exert, on the way to the centre, accelerating influences on the motor fibres in the trunk, along which the efferent impulses might run down extraordinarily fast to make the whole reflex time very much shorter. It is of course an open question if any powerful interaction really takes place or not among fibres in situ. According to Sherrington (2), however, a nerve supplying a muscle contains a great many afferent fibres, amounting at least to 40 % of the whole. It seems then fairly probable that the afferent fibres, at least when excited simultaneously, would do act on the motor fibres.

THE TIME COURSE OF THE ACCELERATING ACTION

How and how long is the accelerating action effective? This is the theme in this chapter. Another question is that, according to Marrazzi and Lorente de Nó (3), the interaction between fibres is exhibited in three successive phases, i.e., in those of suppressed, enhanced and again suppressed excitability. This seems highly probable from theoretical considerations, too, and if so, we are not to expect any enhanced state of excitability to be left in a fibre after the passage of an excitation wave in a neighbouring fibre. But it is really the case in the model. Is it one of the fundamental differences between nerve and model, or is the suppressed phase left unnoticed in the model?

Two cores, I and II, were laid in parallel, a certain definite distance apart from each other. The core I was taken as the accelerator, the influence of which upon the conduction time of the core II was going to be examined. The measurement must be done at a fixed immersion time and that at several intervals after the activation of the accelerator. To fulfil these requirements, we decided to perform the measurement of the (Cond. Time)_{II} at every, say, five minutes, giving the stimulus R_1 to the core I at several short times prior to the stimulus R_2 to the core II. The following schematic illustration will assist to make the scheme clear:

In the above illustration, T represents the interval of two successive R_2 s, that is, the immersion time of the core II, and ΔT the interval between R_1 and R_2 . In this way, we can follow the time course of the accelerating action very simply. The (Cond. Time)_{II} *without* R_1 , that is, the proper (Cond. Time)_{II} uninfluenced by the activation of the core I, was also measured at times during the course of experimentation, in order to examine the temporal variation of the (Cond. Time)_{II} itself.

Again to spare the space, just one of the graphs obtained will be given (Fig. 7).

Fig. 7

We have a number of similar graphs as Fig. 7, in all of which we recognize a sudden decrease of (Cond. Time)_{II} when measured immediately after R_1 . It recovers gradually with time and finally regains its original value after a few minutes usually. Attempts were made to find any of such suppressing phases as were worked out by Marrazzi and Lorente de N6 (3), but in vain. When we shortened the interval, we could only find the sudden decrease more marked in magnitude. Finally we made the interval so short that while the activation wave of the core I was still on the half way, the wave of the core II began to start. A special interest in this case was that the wave II ran after the wave I until it caught up with that and finally went on together with a common "slowed" velocity. (As to the "slowing," see also Katz and Schmitt (4) and Yamagiwa (1).) A similar phenomenon between two nerve fibres was described by Katz and Schmitt, (4). It had been ascertained, beforehand, in the present experiment that the genuine velocity of the core II was certainly smaller than that of the core I, hence the fact observed was nothing but a strong evidence that the effect left behind by the wave I in the core II was of accelerating nature in this case, too. It was also interesting to see, in this case, that the two

waves often strove to go ahead, one leading the other alternatively, before they went on in step finally. This phenomenon was never observed in the case of simultaneous activation of two cores of different velocities (Yamagiwa (1)).

There is another fact to be described here: if the wave I is made to start at a relatively short immersion time, or, physiologically to say, in the relative refractory period, the wave goes on with decrement and stops somewhere on the way. Now, if the wave II is made to pass by just in time when the wave I is almost stopping, the wave I can be revived and go on further in step with the wave II with, seemingly, fresh energies.

SUMMARY AND CONCLUSION

Further studies were made on the accelerating interaction between Lillie's nerve models from various aspects. The results obtained can be summarised as follows:

1. If two cores I and II are activated one after the other with a short interval in between, the activation wave in I makes the conduction velocity of the wave in II always larger than usual, as was previously ascertained, and that
 - a) The action is strengthened if many, instead of one, cores are activated simultaneously to cooperate together as accelerators, and
 - b) The action gets weakened, if a single accelerator has many cores to affect on, instead of one.
2. The intensity of the accelerating action depends on the distance between the cores, i.e., it is the stronger, the smaller the distance is.
3. The direction of the activation wave as an accelerator is insignificant.
4. The accelerating action lasts for a few minutes in general, the intensity being strongest directly after the sweep of the accelerating wave, then dropping acutely to a low value, and then getting weaker and weaker slowly with time.

We don't know yet whether such an accelerating action as observed in the model, does take place in nerve in situ or not. It is obvious, however, that all the results obtained are due to electric interaction, and we know, on the other hand, that there is, in nerve, the "action current," an electric event quite similar to the activation current in the model. We shall have to bear in mind, therefore, that there would sometimes occur an accelerating interaction between nerve fibres in situ, too, although it is not clear at all at present how strong it will be.

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