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**The Effects of Flexor Muscle Spindles and Tendon  
Organs on Homonymous Motoneurones in Relation to  
 $\gamma$ -Bias and Curarization**

By

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### Abstract

BIANCONI, R., R. GRANIT and D. J. REIS. *The effects of flexor muscle spindles and tendon organs on homonymous motoneurons in relation to  $\gamma$ -bias and curarization.* Acta physiol. scand. 1964. 61. 348—356. — The experiments described in the previous paper dealing with extensor motoneurons (Acta physiol. scand. 1964. 00. 000—000) have in this contribution been repeated with the flexor neurons. The major difference between the autogenetic reflexes in the two cases occurs in the phase of post-contraction. While the extensor motoneurons show a drawn-out inhibition, the flexor motoneurons display an equivalent increase of excitability. This difference between the antagonist nuclei is actually a postulate of our interpretation which for good reasons assumes that just after a contraction the spindle secondaries dominate the autogenetic barrage from the muscle receptors. These receptors are known to be inhibitory on extensor motoneurons and excitatory on flexor motor nuclei. The spindle secondaries have thereby been given a role to play in the spinal control of the muscle contraction.

Our previous paper (Bianconi, Granit and Reis 1964) which by monosynaptic testing analyzed the autogenetic effects of stretch and contraction upon extensor motoneurons showed that inhibition by this index was prominent in three experimental situations: (i) as a consequence of stretch maintained beyond a certain length and tension, (ii) during the rising phase of an isometric muscle contraction and (iii) just after the contraction, beginning late in the relaxation phase. The effect during stretch was ascribed to the combined action of tendon organs and muscle spindle secondaries, the inhibition during the rise in contractile tension was explained by the action of the tendon organs supported by

Table I

	Spindle primaries	Spindle secondaries	Tendon organs
Extensors	Excitation	Inhibition	Inhibition
Flexors	Excitation	Excitation	Inhibition

cessation of spindle activity (the pause), and the post-contraction inhibition by the relative dominance of spindle secondaries at this moment, as demonstrated by Harvey and Matthews (1961) and Bessou and Laporte (1962), the latter stimulating  $\gamma$  fibres and recording from secondaries and primaries in the same spindle. In referring below to our previous paper we shall call it Paper I.

Now it is well known that the spindle secondaries which possess afferents in the Group II category (Merton 1953, Hunt 1954), are excitatory on the flexor motoneurons (Laporte and Lloyd 1952, Hunt 1954, Laporte and Bessou 1959). This means that, while these receptors in extensors produce autogenetic inhibition, they should in the flexors produce autogenetic excitation. Thus in the latter one important source of inhibitory impulses from muscular afferents is replaced by a facilitatory source. Golgi tendons organs, on the evidence of Laporte and Lloyd (1952) would be inhibitory in flexors as they are in extensors, at least to the extent that they belong to Group Ib. More complex patterns of Ib action were described by Eccles, Eccles and Lundberg (1957) but these do not seem to be autogenetic. Spindle primaries are excitatory in both flexors and extensors. This comparison between autogenetic effects of extensors and flexors is summarized in Table I o.

From this table emerges that in extensors the autogenetic spindle effects are antagonistic, in flexors synergistic. Thus whenever both spindle organs are excited together, one should expect excitation to dominate in flexors while in extensors this could be the case only if the autogenetic effects of the primaries for some reason were more potent than those of the secondaries. Initially, in contraction, they proved to be so (Paper I). Later on, in the post-contraction phase (Phase IV of Paper I) a long-lasting autogenetic inhibition was found. This effect was ascribed to the secondaries. The explanation presupposes that the equivalent phase in the flexors should be characterized by autogenetic excitation (cf. Table I). One of the chief reasons for extending our work to flexors was to test this proposition.

### Methods

The technique and general procedure is identical with the one described in our previous paper on extensors except that in the present case denervation of the limb left the two flexors, tib. ant. and extensor longus digitorum, with intact nerves. The two muscles were separated and their tendons then joined together to the isometric myograph, care being taken to adjust their lengths to approximately equal values. The ventral

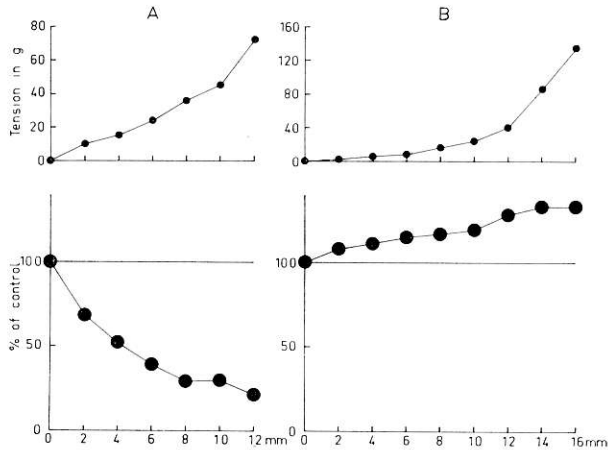


Fig. 1. Autogenetic effect of stretch on the monosynaptic reflex of ankle flexors in the intact (A) and spinal (B) animal. In both diagrams; Abscissae, extension in mm; Ordinate: lower curve amplitude of monosynaptic reflex in per cent of amplitude at initial zero length; upper curve, muscle tension in g.

roots were severed up to and including L6, that of L7 cut in the middle so as to leave a peripheral stump for stimulating the muscle while the central stump was used for recording the monosynaptic response elicited from electrodes on the peroneal nerve at the level of the knee.

As in the previous experiments the animals were anesthetized with pentobarbitone, otherwise they were intact. Spinalization at the level of C1 was carried out in one case.

In all work of this character there is the complication of homosynaptic versus heterosynaptic testing, discussed at some length by Granit and Job (1952), but since our aim is to compare extensors with flexors under similar circumstances we have avoided this issue by using homonymous (homosynaptic) testing in both cases. Both types of experiment will then be contaminated by the same error caused by the afferent barrage in the largest fibres. Of particular interest is again the outcome of the test in the post-contraction phase because at that stage the half-maximal, monosynaptic test response should be a reliable measure of autogenetic excitability in the pools of both extensor and flexor motoneurons and in the two cases the autogenetic effects, as stated, would have to be in the opposite direction. Since the spindles pause during the rising phase of the contraction a comparison of flexors and extensors by homonymous testing would be reliable in this situation too.

Fig. 8 of Paper I subdivides the events from stimulus to end of contraction into four phases which will be used as standards of reference also in the present work.

## Results

In the spinal animal with its flexor pool released (Job 1953, R. M. Eccles and Lundberg 1959, Holmqvist and Lundberg 1959) Henneman (1951), found that stretch causes facilitation of the monosynaptic test response. We have confirmed this on the one spinal animal used whose curves for passive tension and motoneurone excitability are shown in Fig. 1 B. In the intact animals the effect of stretch turned out to be inhibition, just as in the extensors, and this

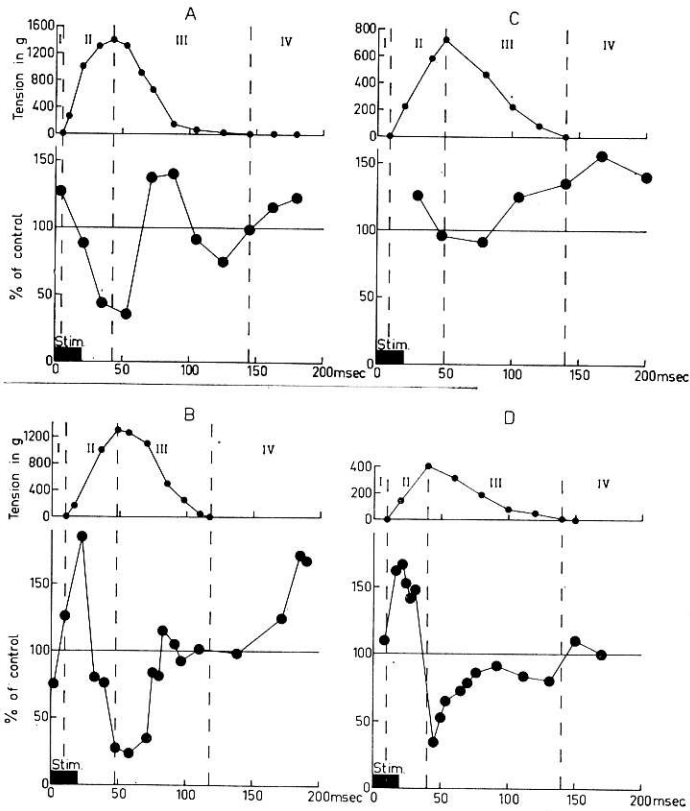


Fig. 2. Time course of autogenetic effects of conditioning L7 stimulation 5 to 10 times a strength on monosynaptic reflex of ankle flexors in 4 different experiments. In each diagram: Abscissae, time in msec from beginning of conditioning stimulation at 500/sec and  $\alpha$ -supramaximal intensity. Ordinate: lower curve, amplitude of monosynaptic reflex in per cent of its unconditioned amplitude; upper curve, muscle contraction in g. I = pre-contraction phase; II = contraction phase; III = relaxation phase; IV = post-contraction phase. Description in the text.

effect as a rule started at extensions as small as to be around 2 mm. Occasionally excitability for the first 2 to 4 mm of extension rose a little but in the end inhibition prevailed. The typical curve is shown in Fig. 1 A (lower graph).

While in the extensors the maximum inhibition brought the test response to zero at extensions around 12 to 14 mm, in flexors the maximal inhibitions ranged from 50 to 80 %. They were never complete.

The difference between extensors and flexors is thus, so to speak, in the right direction in view of the known properties of their sensory afferents acting to determine autogenetic excitability (Table I). There are more inhibitory afferents in the extensors and the spindle secondaries, whose activation requires more stretch than is necessary for the spindle primaries, should in the flexors augment

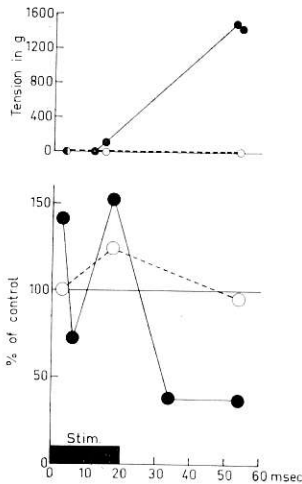


Fig. 3. Example of facilitation in Phase I preceding the facilitation at onset of contraction, and effect of Flaxedil upon it. Abscissae, time from commencement of conditioning stimulation. Duration of this, heavy line. Ordinate: lower curve, amplitude of monosynaptic reflex in per cent of its unconditioned amplitude; upper curve, muscle contraction in g. ● before and ○ after Flaxedil.

autogenetic excitability and never diminish it. The preparation needs but be balanced towards flexor dominance by spinal section to show the expected facilitation to stretch, instead of the complete inhibition so characteristic for the homosynaptically tested extensors.

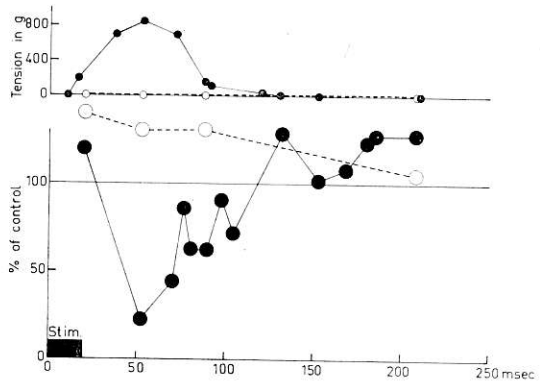
### Contraction

*Survey.* A general survey is given in the four experiments plotted in Fig. 2, all of which compare changes of tension (above) with changes of excitability (below). The stimulus to the ventral root was always supramaximal for  $\alpha$  motor fibres, as measured by the size of the contraction, because, as in the experiments with the extensors, activation of  $\gamma$  fibres was aimed at. Initial tension was moderate, just above the presumed threshold for the spindle secondaries. The separation of the curves into the four phases, marked I—IV, is taken from Fig. 8 of Paper I.

The two experiments, A and B of Fig. 2, are typical of the large majority and show the following sequence of events: facilitation of a very modest order at the foot of the contraction (this effect was large in extensors) increasing into Phase II or quickly supplanted by inhibition while contraction increases (similar to the inhibition in the extensors). Early in the relaxation, Phase III, there may or may not be a hump of rising excitability (just as in extensors) but in the post-contraction in Phase IV there is facilitation in the flexors. In this phase the typical event in the extensor nuclei was inhibition, often profound.

As always in experiments of this kind the central setting of the spinal cord is important and introduces variations. Fig. 2 C represents a case in which the central setting has favoured excitation so that the inhibitory effect during contraction is small. The post-contraction facilitation of Phase IV is always

Fig. 4. Time course of autogenetic changes of ankle-flexor motoneurone excitability (monosynaptic reflex) following conditioning contraction before and after Flaxedil at intensity 8 times  $\alpha$  threshold. Abscissae, time in msec from commencement of conditioning stimulation as indicated by heavy line. Ordinate: lower curve, amplitude of monosynaptic reflex expressed in per cent of its unconditioned amplitude; upper curve, tension in g. ● before and ○ after Flaxedil.



seen in such cases. Finally Fig. 2 D is an example of two experiments in which the post-contraction facilitation was relative only. The contraction was small. Nevertheless there was good inhibition which disappeared with the disappearance of tension.

*Phase I.* The facilitation which as a rule was smaller in flexors than in extensors began before the myogram displayed a rise of tension. Occasionally, as in Fig. 3, it was separated from the facilitation in Phase II which is synchronous with the onset of measurable contraction. Curarization by Flaxedil suffices to remove facilitation in Phase I (Fig. 3). It did not remove it in the extensors.

*Phase II.* The inhibition during the rise of tension disappeared after Flaxedil, as shown in Figs. 3 and 4, and was replaced by facilitation when contraction was blocked. Such facilitations lasted for a longer time in flexors than in extensors, in fact during the whole of Phase III. Increase of stimulus strength to 8 to 10 times the  $\alpha$  threshold reduced the inhibition.

*Phase III.* More often than in extensors the maximum inhibition was slightly delayed with respect to maximum tension. The transient facilitation, which occurs in both extensors and flexors, was in the former identified with the 'myotatic hump' or 'appendage' of Ballif, Fulton and Liddell (1925). It is similarly interpreted in the flexors. In both cases it is dependent upon 'natural' spindle activation caused by the pull on the sense organ in relaxation. It was absent after Flaxedil (Fig. 4) when the tension changes had disappeared.

The use of Flaxedil in our experiments is based on the fact that for some time after complete block of the  $\alpha$  motor end plates the  $\gamma$  terminals still are capable of activating the intrafusal muscles as judged by the increased spindle discharge after strong tetani (Granit, Homma and Matthews 1959), repeatedly confirmed in this laboratory and now again checked with flexor spindles. The selective block is, however, more reliable with extensors in which the average dose of 2 mg/kg wholly removed contraction while the spindles still functioned practically undisturbed for some 15 to 30 min or more. In flexors the margin between  $\alpha$  and  $\gamma$  block is narrower. The dose of 2 mg/kg did not suffice for complete extrafusal block and with slightly larger doses the time available

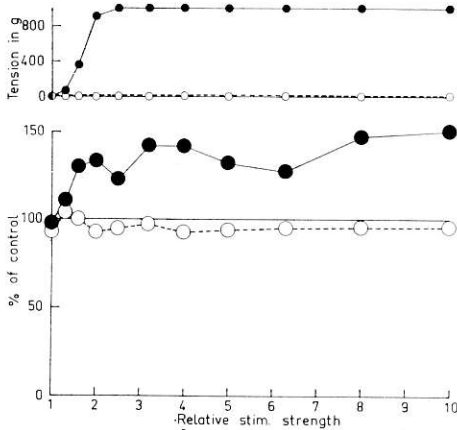


Fig. 5. Relationship of conditioning stimulus strength to muscle contraction and motoneurone excitability. Abscissae, conditioning stimulus intensity as multiples of threshold for contraction. Ordinate: upper curve, tension in g at maximum of contraction; lower curve, amplitude of monosynaptic reflex in post-contraction phase (190 msec after commencement of conditioning stimulation). ● before and ○ after Flaxedil.

for good spindle activation was shortened to a few minutes only, which means that the time course of flexor motoneurone excitability after Flaxedil had to be tested against a background less constant than with extensors.

*Phase IV.* In extensors the inhibition after relaxation did not appear unless the muscle actually had contracted and hence it was absent after Flaxedil. There is a general similarity in this respect between the two antagonist motor nuclei in spite of the fact that Phase IV is excitatory in flexors and inhibitory in extensors. After Flaxedil in Fig. 4 facilitation diminished. In Fig. 5 it is seen that post-contraction facilitation as a function of stimulus strength runs parallel with the increase of the contraction and fails to be further increased by stimuli (the early tetani shown in the other experiments) reaching well beyond the  $\gamma$  threshold. After Flaxedil the post-contraction facilitation is gone. In every respect therefore the post-contraction changes of excitability in the two antagonist motor nuclei behaved as if similar events in the muscle receptors had acted in opposite direction on their executive organs, the motoneurons.

### Discussion

In extensors there is a quite powerful rise of excitability with a latent period as short as 3 msec (Granit 1950), again confirmed in our Paper I. Part of it may have been caused by the ephaptic component of stimulation, the so-called 'back-response' (Lloyd 1941, 1942, Leksell 1945) analyzed by Granit, Pompeiano and Waltman (1959) in its dependence on tension and extension. They found ephaptic excitation less prominent in the flexors used above than in the ankle extensors. When now the facilitation in Phase I also is less prominent in flexors than in extensors it may well mean that ephaptic excitation is more important than our work on extensors suggested. We were surprised there to find the facilitation of Phase I insensitive to Flaxedil, because, according to Lloyd (1942), curarization should depress ephaptic excitation.

The 'early discharge' from muscle receptors in contraction (the term being Hunt and Kuffler's 1951) was found to have a second component (Granit, Pompeiano and Waltman 1959) synchronous with contraction, difficult to distinguish from the ephaptic component in extensors but visible in flexors in which its existence also has been demonstrated in flexor reflexes (Rutledge and Haase 1961). This component of the early discharge has been ascribed to  $\alpha$  spindle activation which since has been clearly demonstrated by direct recording in the cat's toe flexor (Bessou, Emonet-Denand and Laporte 1963). Presumably this is responsible for the early facilitation preceding the inhibition that further tension development engenders (Phase II).

Autogenetic inhibition dependent on tension in contraction is well known from work on extensors, the relevant literature being referred to in our Paper I. We found this effect to disappear after Flaxedil. In this respect flexors and extensors behave similarly. In the latter it has generally been identified with the Group I disynaptic inhibition of Laporte and Lloyd (1952), nowadays often called Ib and shown to contain in addition a number of polysynaptic links (Eccles, Eccles and Lundberg 1957). Laporte and Lloyd found this type of inhibition also in flexors and so there is some reason for extending identification of Ib or tendon organ inhibition to the present finding in flexors in which it now has been shown to be autogenetic and tension-dependent.

The 'myotatic hump' in Phase III has already been identified with the equivalent event in the extensors (above and in Paper I).

The finding which to us seems of greatest interest in the present work is the post-contraction excitation in Phase IV. It has already been pointed out that this event is a replica with opposite sign of a similar process in the extensor motoneurons, in them ascribed to the effect of spindle secondaries. It is not necessary here to repeat more than one argument for this identification, namely the fact that secondaries are known to excite the flexor reflex (Hunt 1954, R. M. Eccles and Lundberg 1959, Laporte and Bessou 1959) which means that they are inhibitory for extensor nuclei and excitatory for flexor nuclei, as required by our identification of the two post-contraction events with opposite sign in the antagonist nuclei. It follows that the changes of autogenetic excitability in Phase IV cannot be a consequence of engagement as such of motoneurons leading to refractoriness. Such processes would be of identical sign in flexors and extensors.

We have no basis for evaluating the relative role of pre- and postsynaptic inhibitions in this paper (cf. Eccles, Eccles and Magni 1961) and have therefore restricted interpretation to the probable peripheral events in the muscle receptors. Clearly, however, the experiments have provided a basis for an experimental identification of the inhibitory processes concerned.

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