

EXTERNAL CONTROL OF EXCITATION AND INHIBITION IN
TRANSECTED SPINAL CORD OF MAN

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SUMMARY

This paper gives a brief review of the neurophysiological features of the reflex motor organization in spastic spinal paraplegia. These features are discussed of their potential usage in, or disadvantage to, the attempts at external control of movement. There are essentially two systems of reflexes--monosynaptic stretch reflexes and polysynaptic cutaneo-muscular reflexes, exemplified by the flexion withdrawal reflex.

The problems in using these reflexes for externally controlled movement are the large range of spontaneous, apparently random, quantitative variation when elicited repetitively, habituation, and stereotyped patterns of the resulting movement. Another difficulty is the predominance of excitatory over the inhibitory mechanisms, particularly in incomplete spinal cord lesions. The possible solutions to some of these problems are discussed. Vibration is proposed as a powerful artificial support to the physiological servo-control in patients with incomplete lesion. A neurophysiological study model for external control of excitation and inhibition in a motoneurone pool is described. Guidelines for future efforts in this type of approach to external control of movement are discussed.

In the recent years a number of research groups have approached the problem of loss of voluntary movement in patients with various lesions of the neural and muscular system. A variety of possible solutions have been studied. In paraplegia due to transverse spinal cord lesion the reflex excitability of the motoneurone pools below the level of lesion remains preserved, and the possibility of using the so-called afferent stimulation for external control of movement has been repeatedly considered (1,2,3). The first of our three papers in this volume will discuss this possibility, briefly reviewing the neurophysiological mechanisms available for attempts at external control, as well as the problems anticipated.

The basic phenomena of spinal paraplegia have been recognized since the classical Sherrington's description of spinal cat (4). Following a stage of suppression of all reflex activity below the transection immediately after the injury, i.e., the condition of spinal shock, there is gradual return of reflexes, the first being the flexion withdrawal reflex. Next to reappear are the perianal reflexes as well as the myotatic or stretch reflexes. All these gradually increase in intensity and in a few months there are two dominant patterns of reflex motor activity: exaggerated flexion withdrawal reflex on the one hand and exaggerated phasic and tonic stretch reflexes associated with clonus on the other hand.

In our previous reports to Symposia on External Control of Human Extremities

(1,2) we have discussed the possibilities of reorganizing and exploiting this motor activity so that it might subserve some functional movement.

Before further discussing the above question we should like to give a brief summary of neurophysiological characteristics of the flexion withdrawal reflex and the stretch reflex in spinal paraplegia, which we have studied extensively in the past years (5-12).

The flexion withdrawal reflex is a cutaneo-muscular reflex based on a polysynaptic reflex arc extending through several segments of the spinal cord (Figure 1).

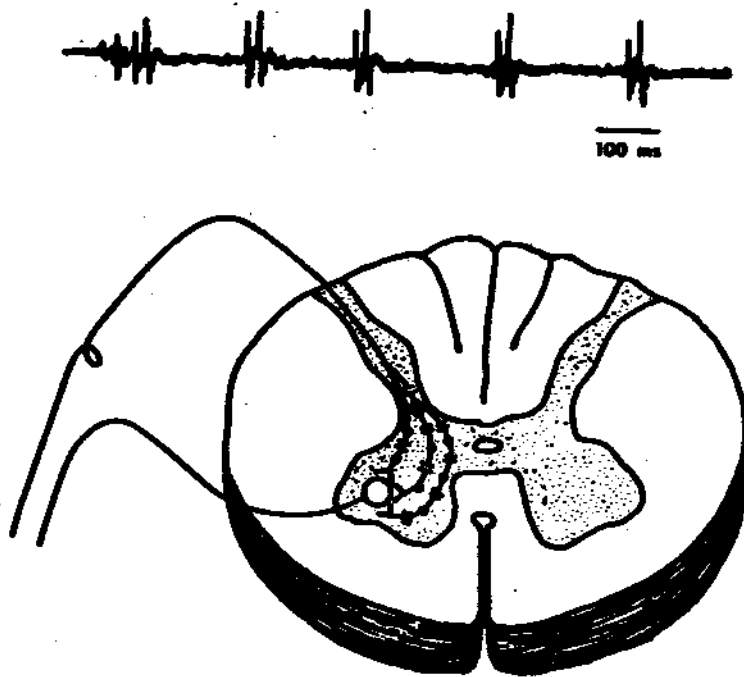


Figure 1

In the paraplegic patients it has abnormally low threshold, larger reflexogenic zone and it involves an increased number of muscle groups, which results in a stereotyped massive withdrawal movement from the offending stimulus. The amount of the movement depends not only on the strength of the stimulus, but also on the number and frequency of previous stimulus presentations. Repetitive

stimulation tends to produce habituation, that is, gradual decrease of the response. Increase in stimulus strength or irregularity in stimulation rate will interrupt habituation. Both habituation and dishabituation are processes variable in intensity as well as in time constants, and can be partly controlled by changing stimulation patterns (Figure 2).

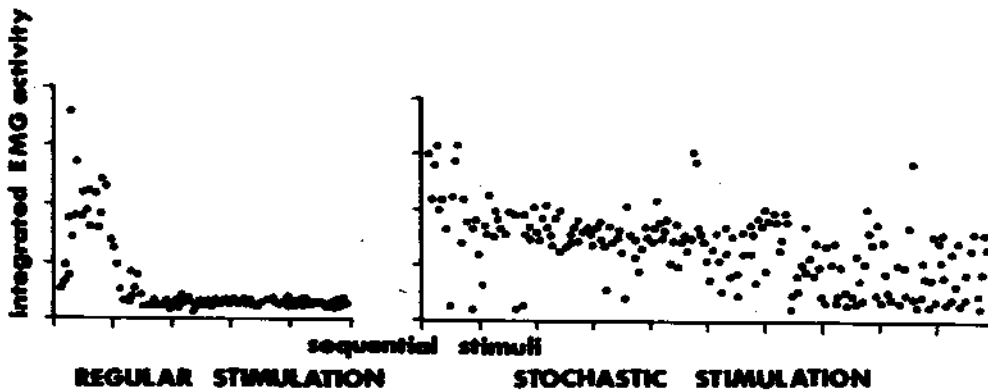


Figure 2

The phasic stretch reflex or tendon jerk is based on a monosynaptic reflex arc (Figure 3). The most distinguishing feature of the phasic stretch reflex in spinal paraplegia as compared to the normal condition is that the initial response is followed by an after-discharge. Also, the reflex has a decreased threshold and is abnormally brisk. Sustained stretch can induce clonus, which appears to be composed of a series of stretch reflexes separated by periods of inhibition. The stretch reflex is also subject to processes of habituation and dishabituation (Figures 4 and 5), although usually somewhat less conspicuous. In contradistinction to the polysynaptic reflexes, such as the flexion withdrawal reflex, it can be potentiated with high frequency (tetanic) afferent inflow.

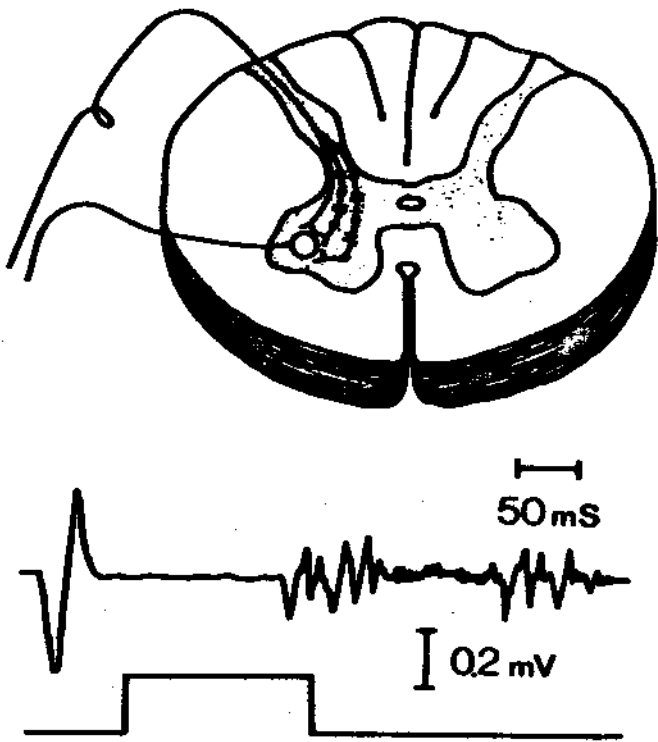


Figure 3

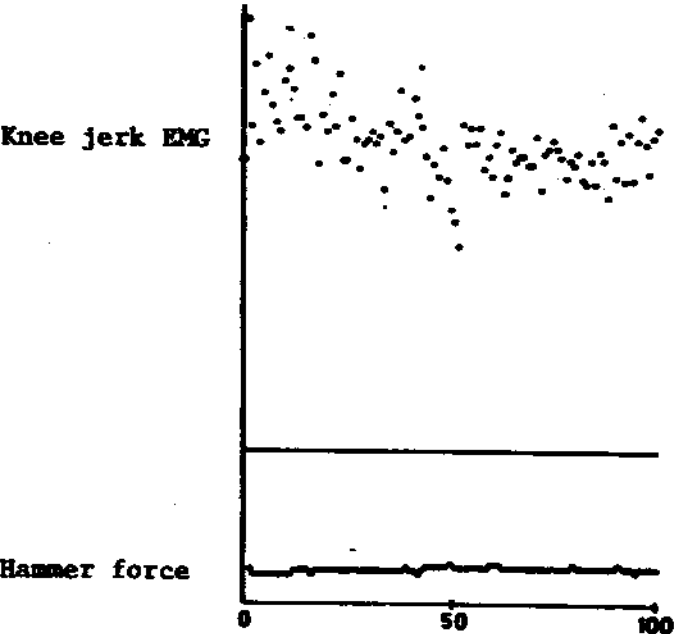


Figure 4

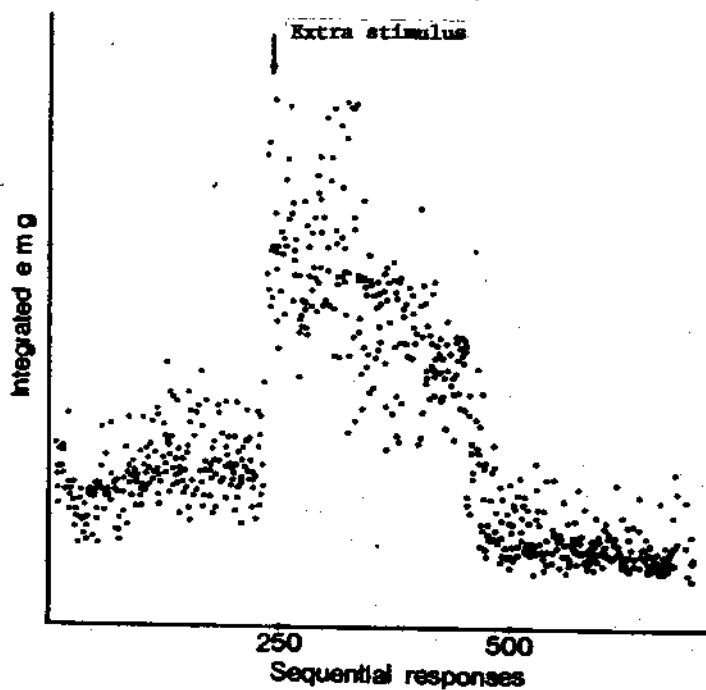


Figure 5

So, the motoneurons in spinal paraplegia appear to be abnormally ready to fire both in the polysynaptic flexion withdrawal reflex and in the monosynaptic stretch reflex. This abnormal availability is the mechanism underlying spasticity and is due to an increase in background excitation both of the spinal motoneurone pools and in the system of the propriospinal interneurons. This in turn is due to the lack of supraspinal descending inhibitory modulation of spinal motoneurons and interneurons. It is of interest to note that spasticity is usually less severe in patients with complete transverse division of the cord, which shows that the remaining descending fibers tend to facilitate rather than inhibit excitation, sometimes quite considerably, even when they are too few to initiate any useful movement (12).

After this brief review, let us again consider the possibilities and problems of using the neurophysiological mechanisms in the external control of movement.

Any movement and indeed any organized activity in the central nervous system depends on an appropriate control over two mechanisms: excitation and inhibition. The problems in spastic spinal paraplegia are that excitation is

coarse, easily spread, stereotyped and subject to habituation. Inhibition is poor, and is easily overridden by excitatory processes.

Habituation can be overcome by either increasing the stimulus strength or changing the spatial or temporal patterning of the stimulation (Figure 6, see also Figures 2 and 5).

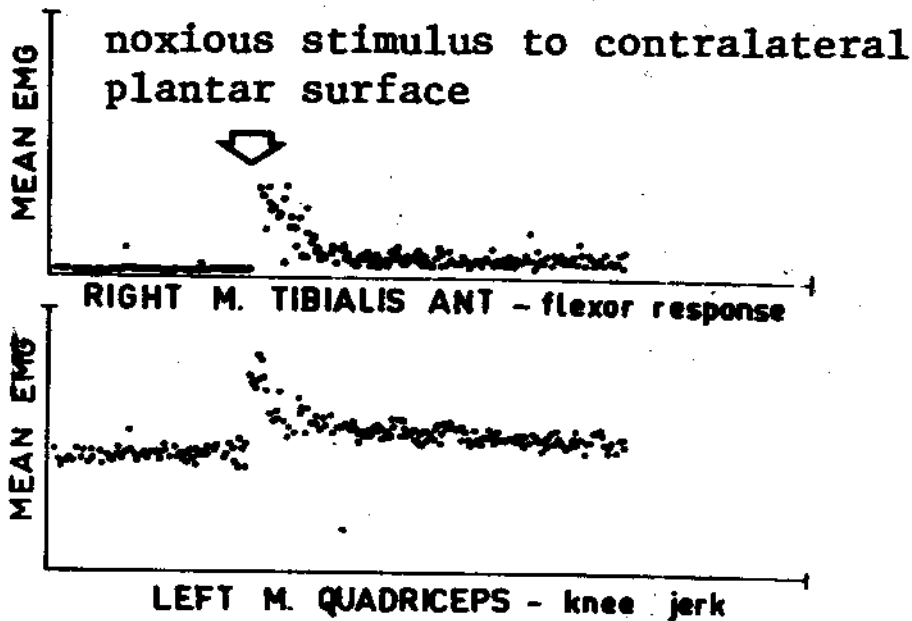


Figure 6

In our earlier work (13) it has been shown that even at the level of the spinal cord habituation may be based, at least in part, on recognition of simple to rather complex stimulus patterns, and not just on simple synaptic fatigue in multineurone pathways as proposed by Spencer, Thompson and Neilson (14). Thus dishabituation could be produced by a change in stimulation pattern not implying any net increase in stimulation energy per unit of time or changing to other sensory inputs. However, this mechanism is usually less easy to demonstrate and probably does not play a major role in this condition; for most practical purposes in externally controlled dishabituation it should suffice to consider that the easiest and most efficient way is to increase the stimulus, or use stochastic changes in stimulus parameters or employ additional input channels. We have shown high input specificity for habituation moving

the stimulus only a few centimeters from the original position results in dishabituation.

An interesting possibility for external control of excitation is offered by vibration. Hagbarth and Eklund (15) have demonstrated that in incomplete upper motor neuron lesion vibration of paretic muscles can increase strength of voluntary contraction. In a recent study (12) we have shown that vibration in combination with voluntary effort may produce a good movement even when there is no other evidence of partial preservation of descending pathways and the patient is regarded to have a complete lesion (Figure 7).

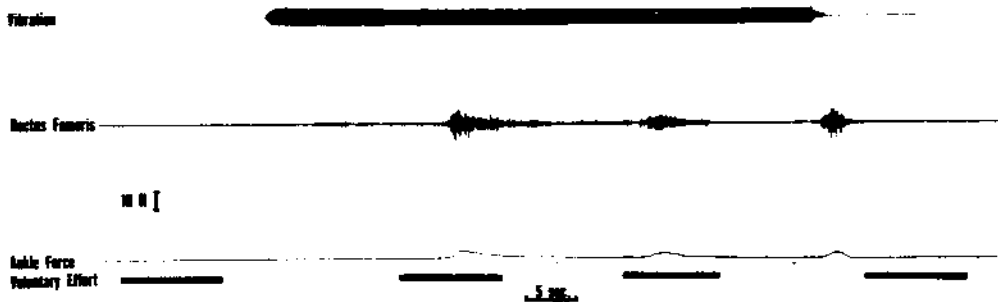


Figure 7

It is possible to speculate that voluntary effort in this case works not so much on the alpha-motoneuron pool but predominantly on the gamma-motoneurons thus allowing a tonic vibration reflex to develop. The advantage of this type of artificially supported servo control is that voluntary effort will trigger the contraction much as in the normal condition, and that the

antagonistic muscles are simultaneously depressed.

As regards the possibility for externally controlled inhibition, there is a variety of inhibitory reflexes whose arcs are completed and preserved in the stump of the spinal cord. For the purposes of external control the most interesting ones may be those elicited by stimulation of cutaneous nerves. This inhibition is mainly presynaptic. A problem could be that such stimulation may also produce excitatory responses, e.g., the flexion withdrawal reflex. However, on repetitive stimulation excitation will habituate much faster than inhibition, and this should make it possible to achieve inhibition uncontaminated with undesired motor responses after an initial period of stimulation.

To study the feasibility of external control of excitation or facilitation and inhibition or depression in a given motoneurone pool of a paraplegic patient we chose the following experimental situation (16).

The motoneurone pool to be controlled was that of the quadriceps muscle of one leg. The effect of the external control was tested as changes in magnitude of repetitively elicited stretch reflex of the quadriceps. Externally induced facilitation was achieved by stimulating the contralateral plantar surface with light noxious stimuli. The physiological basis of this is the crossed extensor reflex. Externally induced inhibition of the quadriceps motoneurone pool was achieved by light noxious stimulation of the ipsilateral plantar surface. Both facilitation and inhibition have characteristic time courses necessitating appropriate intervals, mainly between 50 and 500 msec., and can be graded by grading the strength of the noxious stimulus. This experimental model has been used in the cybernetic study which will be reported in the third paper of this series.

It must be emphasized that the described effects of conditioning facilitatory and inhibitory stimulation are subject to similarly large variations as described above for the testing response. Thus the "spontaneous" variation is due to undefined synaptic inflows both from the periphery and from some interneurons. Full urinary bladder or an infected decubital ulcer, for instance, may profoundly alter the reflex activity. This tends to severely limitate the constancy and repeatability of the effects of stimulation and, as will be shown in the following two papers, it is necessary to use very complex algorithms to achieve more or less predictable, stable responses.

In spite of the described difficulties it is our belief that this type of approach should be developed further. There is still much to be learned about the reflex organization of the spinal cord and this knowledge might considerably increase our possibilities for external control.

Furthermore, we feel that another fruitful approach for externally controlled excitation and inhibition might be in attempts to induce long-term changes in reflex activity, especially when applied in early stages after injury. Structural synaptic changes have been described to follow long-term afferent stimulation in the isolated spinal cord of the cat (17). We can hope to achieve such structural reorganization as would result in a favorable change of reflex motor patterns. Moreover, externally controlled excitation and inhibition may increase the efficacy of the weak voluntary motor control in patients with incomplete lesions.

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