

PRESYNAPTIC INHIBITION OF THE MONOSYNAPTIC REFLEX BY VIBRATION

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SUMMARY

In cats, the monosynaptic reflex (MSR) elicited from L7 or S1 dorsal roots, or from the tibial nerve (H reflex) was suppressed by vibration at 50–500 c/s of the hind limb with innervation intact. The MSR was not suppressed by selective vibration of cutaneous receptors, and suppression was still observed after the hind limb was skinned. In contrast, the phenomenon disappeared when all muscle nerves were crushed.

Suppression of the MSR by vibration was shown to be mediated by presynaptic inhibition by the following methods: correlation with onset of the dorsal root potential (DRP) evoked by vibration, and abolition of both DRP and reflex suppression by picrotoxin; demonstration of primary afferent depolarization and normal excitability of motoneurons to direct stimulation.

Reasons are given for deducing that the muscle afferent fibres responsible for the presynaptic inhibition induced by vibration are group Ia rather than groups Ib or II, or afferent fibres from Pacinian corpuscles.

INTRODUCTION

Phasic reflexes (tendon jerks and H reflexes) are reduced or abolished in man when a vibrator is applied to the appropriate muscle or tendon. At the same time a tonic reflex contraction usually develops in the muscle vibrated (Lance, 1965, 1966; de Gail, Lance & Neilson, 1966; Hagbarth & Eklund, 1966). Vibration-induced tonic contraction has been

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studied by Matthews (1966) in the decerebrate cat. Tonic contraction and phasic reflex suppression have been shown to be independent phenomena by their response to Ciba 28,882 Ba, diazepam, benztropine methanesulphonate and thiopentone, which block the former but not the latter (Lance, de Gail & Neilson, 1966). Moreover, in spinal man, vibration suppresses phasic reflexes although the tonic contraction is either absent or altered in character.

Muscle spindles are sensitive to vibration although they probably play no part in its perception. Echlin & Fessard (1938) reported that muscle afferents of frog and cat discharged at the same frequency as a tuning fork applied to the tendon if the muscle were stretched. This holds true in the cat up to vibration frequencies of 200 c/s when muscle is relaxed (Hunt, 1961). The endorgans responsive to vibration were shown (Bianconi & Van der Meulen, 1963) to be those with afferent fibres of high conduction velocity. Brown, Engberg & Matthews (1967) showed that primary spindle endings responded to longitudinal vibration up to 500 c/s when the muscle was under slight initial tension. They found that secondary endings were very insensitive and could not be driven at 150 c/s or above. Golgi tendon organs were also insensitive to vibration when the muscle was not contracting, and even when the muscle was contracting could not be driven at frequencies greater than 250 c/s. It is therefore probable that the physiological effects of vibration applied to muscle tendon are the result of repetitive stimulation of primary spindle endings and activation of Group Ia afferent fibres.

The apparent paradox of phasic reflexes being suppressed by vibration while a tonic reflex was elicited suggested the possibility of two different types of motoneurone which responded differentially to the reflex effects of vibration, similar to the tonic and phasic reactions described by Granit, Henatsch & Steg (1956) for cat motoneurons. This is unlikely to be the case in man, since Lance *et al.* (1966) were able to demonstrate that the same motor unit participated in both tonic and phasic reflexes in human soleus muscle.

Observations in cat and man have shown that occlusion produced by vibration-evoked activity in peripheral nerve is insufficient to account for the diminution or abolition of the monosynaptic reflex by vibration (Lance, Neilson & Tassinari, 1968; Gillies, Lance & Tassinari, 1969).

The present study provides evidence that the phenomenon is caused by presynaptic inhibition.

METHODS

Twenty-seven cats were anaesthetized by pentobarbitone (30–35 mg/kg intraperitoneally) and three were decerebrated under halothane anaesthesia. The animals were usually given sufficient anaesthetic, or were spinalized, to prevent vibration-induced tonic contraction of muscle. The rectal temperature was maintained at approximately 37° C by an electric blanket. The animal was suspended by a spinal clamp and sacral pins in the spinal attachment of a Kopf stereotactic apparatus. The lower limbs were extended by a steel pin inserted through the calcaneum or lower tibia which was then clamped in a suitable position to maintain tension on the triceps surae. The spinal cord was displayed by laminectomy from the second to the seventh lumbar vertebra, and submerged in a pool of liquid paraffin. The first sacral (S1) or seventh lumbar (L7) dorsal nerve root was gently separated and suspended on a pair of hooked platinum electrodes for stimulating or recording. Nerves in the popliteal fossa were dissected free and the area formed into a pool filled with liquid paraffin. Muscles were not denervated unless specifically stated in the text. Paraffin pools were maintained at a temperature of approximately 37° C by radiant heat and immersed light bulbs. Bipolar electrodes were employed for stimulating or recording from the sciatic nerve or its branches supplying muscle. For monopolar recordings from the anterior root, or for recording DC potentials from the dorsal root, an indifferent silver–silver chloride electrode was inserted into the back muscles. Dorsal root potentials were recorded by a silver–silver chloride electrode, DC amplifier and Offner Dynograph. In order to test the excitability of group Ia terminals by antidromic stimulation (Wall, 1958), a tungsten micro-electrode, tapered to 2 μ and insulated to the tip, was inserted into the spinal cord through the dorsal root entry zone.

Vibration was applied to the tendo Achillis by a rubber applicator attached to a Duo physiotherapy vibrator (Kurt Stoll KG., Neidlingen/Teck., Germany) at a frequency of approximately 50 c/s, the amplitude being such that vibration waves could be recorded by a piezo-electric crystal over all hind limb muscles. In three experiments, the tendo Achillis was dissected free and attached to a Ling-Altec type 201 vibrator which could be driven at any frequency up to 500 c/s.

Stimulating pulses were 0.2–5.0 V, 0.01–0.5 msec in duration. The amplified responses were photographed from the screens of a Tektronix 564 storage oscilloscope by a Tektronix oscilloscope camera, using Polaroid-Land film, or photographed from a Tektronix 560 oscilloscope by a Grass Kymograph camera. Evoked responses were averaged in three experiments by an ND 801 Enhancetron. Statistical comparisons were made by Student's *t* test.

RESULTS

Suppression of the monosynaptic reflex by vibration

The MSR was elicited by stimulation of the seventh lumbar or first sacral dorsal roots and recorded from the hamstrings, soleus or flexor digitorum brevis muscles in seven cats. The MSR was abolished or depressed to less than 30 % of control levels by vibration of tendo Achillis (Fig. 1*a*). The MSR recorded in flexor or extensor muscle groups suppressed equally and there was no difference noted between intact anaesthetized, decerebrate and spinal animals. Toward the end of some experiments, the

reflex failed to suppress with vibration; this was attributed to deterioration in the preparation.

The H reflex was most easily elicited by stimulating the tibial nerve and recording the electromyogram (EMG) from flexor digitorum brevis. The H reflex was identified by its latency of approximately 8 msec, its suppression with repetitive stimulation at frequencies greater than 10/sec and its replacement by the direct muscle (M) response at higher

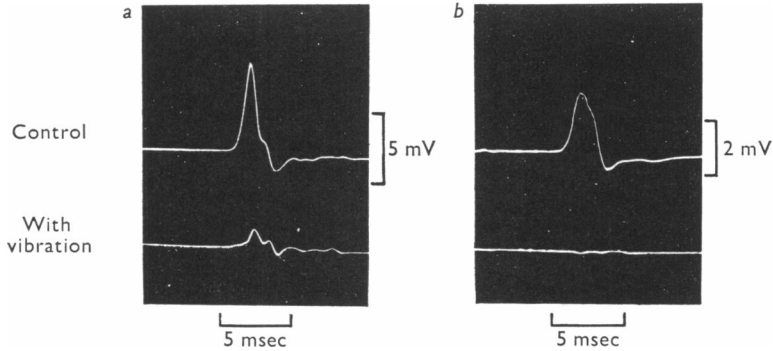


Fig. 1. Electromyogram from cat flexor digitorum brevis showing the suppression by vibration of (a) the monosynaptic reflex produced by stimulation of the seventh lumbar dorsal root; and (b) the H reflex elicited from the tibial nerve.

stimulus intensities. The H reflex was invariably reduced in amplitude or suppressed by vibration in the range of frequencies 50–500 c/s (Fig. 1b).

In many preparations, the F wave was also recorded, and was recognized by its variable latency and its persistence with increased stimulus intensity and with repetitive stimulation at high frequencies. The F wave was unaffected by vibration. The direct muscle (M) response was also unaltered by vibration.

The relative importance of cutaneous and muscle receptors in the suppression of the monosynaptic reflex by vibration

In six cats, the MSR evoked by stimulation of the nerve to soleus was recorded from the cut seventh lumbar ventral root following a single afferent volley, paired afferent volleys separated by 4 msec, or a single afferent volley in the phase of post-tetanic potentiation. Vibration of tendo Achillis consistently reduced the amplitude of the ventral root volley to a mean of 42% (s.d. 16%). After crushing the nerve to soleus distal to the stimulating electrode, vibration continued to suppress the ventral root response to a mean of 63% (s.d. 18%). This was significantly less suppression than before ($P < 0.01$).

To ascertain the importance of cutaneous afferents in reflex suppression, a large flap of skin was removed from the calf and paw with its nerve supply intact and was vibrated in a position such that vibration was not transmitted to the animal. The MSR was elicited by stimulation of the nerve to soleus and recorded from the cut end of the seventh lumbar ventral root. The ventral root discharge was not reduced by cutaneous vibration. The skin of the hind limb was then entirely removed, with the exception of the foot pads. Vibration of tendo Achillis in the flayed limb was as effective in suppressing the monosynaptic reflex as it had been in the intact animal.

In one cat, all dorsal roots with the exception of the seventh lumbar, and all ventral roots were severed. The MSR evoked from the nerve to soleus was recorded from the cut end of the seventh lumbar ventral root and the effect of vibration of tendo Achillis was examined before and after section of muscle nerves. The reflex continued to be suppressed after section of the lateral popliteal nerve, tibial nerve, nerves to medial and lateral heads of gastrocnemius, and the nerve to soleus distal to the stimulating electrode. The response vanished when the remaining branches from the sciatic nerve to thigh muscles were sectioned.

Evidence for presynaptic inhibition

In four cats, DC recordings were made from a silver-silver chloride electrode placed on the cord at the point of insertion of the L7 dorsal root. Simultaneous recordings of the DRP were made from a fine, separated cut filament of the same dorsal root. During vibration a slow potential of 750 μ V was recorded from the cord dorsum (Fig. 2). This was identical in appearance and time course with the DRP recorded from the cut filament, which was shown to be conducted electrotonically from the cord dorsum.

The MSR evoked by stimulating the L7 dorsal root at 1/sec was recorded simultaneously with the DRP. The time taken for the DRP to achieve its maximum amplitude varied from one to 15 sec in different experiments, and its augmenting phase correlated well with the progressive depression of the MSR by vibration (Fig. 3). In contrast to this, the MSR returned to previbration levels more rapidly than the decay of the DRP when vibration stopped. This may be attributed to post-vibration facilitation of the MSR which could be observed with vibration frequencies as low as 50/sec.

Picrotoxin was administered intravenously to three cats at the conclusion of the experiment. After 1 mg/kg, the vibration-induced DRP was reduced proportionately more than the concomitant suppression of the MSR. When a dose of 2 mg/kg was given, the DRP could no longer be recorded and the MSR could not be suppressed by vibration. In three experiments, in which the preparation had deteriorated as the result of

hypoxia or hyperpyrexia, vibration did not suppress the MSR and no DRP could be recorded in response to vibration.

Excitability of motoneurons to direct stimulation remained unchanged during vibration while the MSR was suppressed. In three cats, a micro-electrode was inserted into the dorsal root entry zone of the seventh lumbar

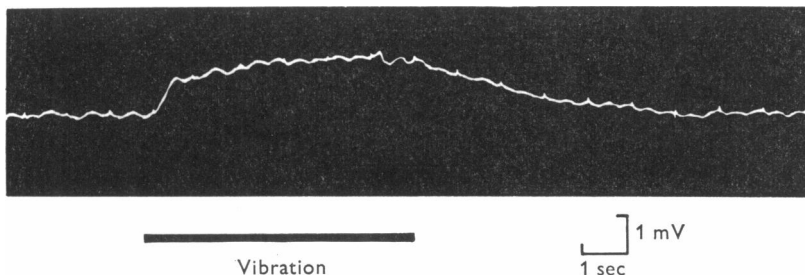


Fig. 2. Cord dorsum potential recorded from the seventh lumbar dorsal root during vibration of the lower limb.

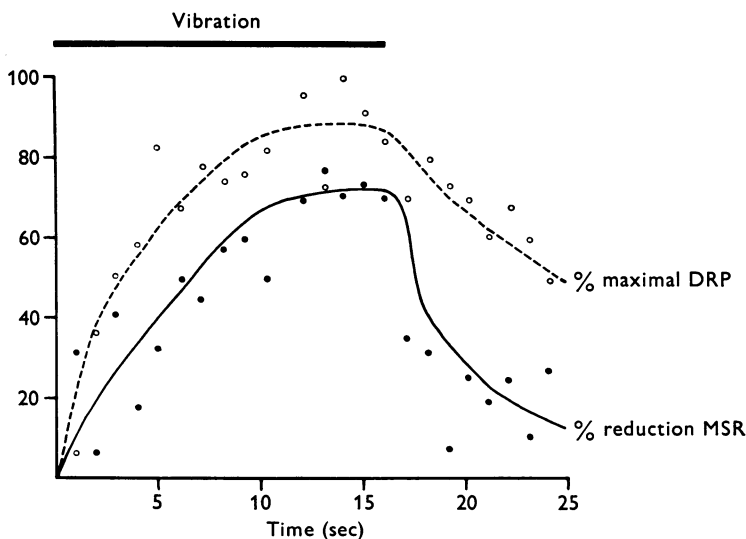


Fig. 3. Correlation of the suppression of the MSR with the development of a DRP.

segment and angled approximately 25° laterally. At a depth of 2.5 mm, adjustment of stimulus voltage produced two ventral root volleys, the first being caused by direct electrical stimulation of anterior horn cells, and the second being caused by synaptic discharge. Vibration of the limb profoundly depressed monosynaptic reflex discharge without alteration of the direct volley (Fig. 4).

Primary afferent depolarization could be demonstrated during vibration.

With a stimulating micro-electrode inserted as described in the previous paragraph, antidromic volleys were recorded from nerve to soleus in three cats. While the tendo Achillis was vibrated, submaximal antidromic potentials were consistently augmented (Fig. 5). Such augmentation could be demonstrated with the stimulating electrode inserted into the spinal cord to a depth of 3.5 mm in the region of group Ia terminals (Wall, 1958).

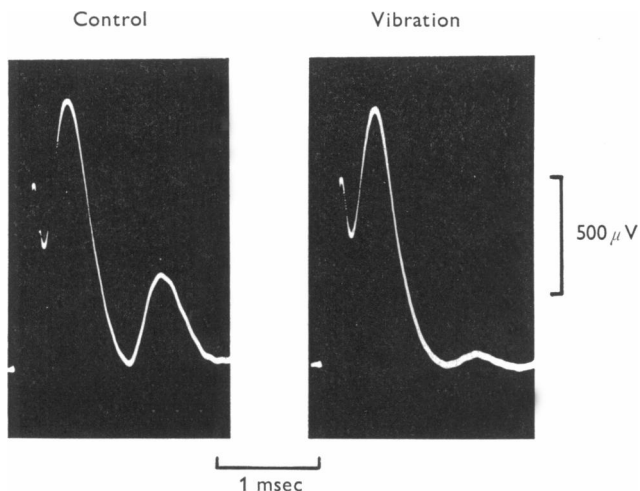


Fig. 4. Ventral root recording of direct motoneurone volley and MSR, showing selective suppression of the latter by vibration of the limb.

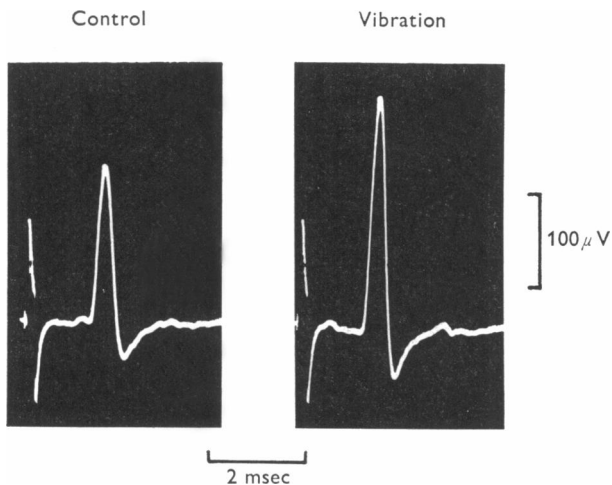


Fig. 5. Antidromic volley evoked by intraspinal stimulation of group I fibres, recorded from nerve to soleus. Augmentation of the response during vibration indicates primary afferent depolarization.

DISCUSSION

The MSR, whether elicited from peripheral nerve or dorsal root, was suppressed by vibration of the limb. When the MSR was recorded from muscle with the efferent limb of the reflex arc intact, it was suppressed to 30% or less of its control amplitude and was often abolished completely. When the efferent limb was interrupted so that the MSR could be recorded from the ventral root, the MSR was suppressed to a mean of 42%. This discrepancy can probably be accounted for by the absence of normal gamma efferent activity in the latter preparation, which would decrease the sensitivity of muscle spindles to vibration (Brown *et al.* 1967).

Peripheral occlusion of afferent impulses does not play a significant role in the suppression of the monosynaptic reflex by vibration, since crushing of nerve to soleus distal to the point of stimulation on the nerve did not prevent the phenomenon. The monosynaptic reflex must therefore be inhibited by afferent activity induced by vibration in nerves other than the one being stimulated.

It has been shown that reflex suppression depends upon afferent impulses from muscle nerves, not cutaneous nerves. Endorgans in muscle and its insertions which are particularly sensitive to vibration are Pacinian corpuscles and primary endings of muscle spindles. Afferent impulses from Pacinian corpuscles are unlikely to be responsible for reflex suppression, since repetitive firing of these endorgans produced by vibration does not affect the MSR of flexor muscles (McIntyre & Proske, 1968) or of triceps surae (A. K. McIntyre, personal communication). Golgi tendon organs and secondary spindle endings are relatively insensitive to vibration and it is improbable that they play any part in reflex suppression on other grounds. Vibration diminishes or abolishes the MSR in flexors as effectively as in extensors, which would not be the case were group II fibres responsible. Reflex suppression is not enhanced by muscle contraction (de Gail *et al.* 1966) as would be expected were group Ib fibres implicated. Moreover, if group Ib or group II afferents were responsible for the phenomenon, it should be more readily elicited in the spinal animal since post-synaptic inhibition by group Ib, and both pre- and post-synaptic inhibition by flexor reflex afferents, is released from brain stem control by spinalization (Lundberg, 1964; Engberg, Lundberg & Ryall, 1968). In fact, there was no significant difference between the degree of MSR suppression in decerebrate and spinal cats. The group Ia afferent fibres from primary spindle endings remain as the most probable mediator of vibration-induced reflex suppression.

The F wave persists after section of dorsal nerve roots (McLeod & Wray, 1966) and is presumed to be due to antidromic activation of moto-

neurones in the spinal cord, hence providing an index of their excitability. Since the F wave is not suppressed by vibratory stimuli, one may deduce that the excitability of motoneurones is substantially unchanged during vibration. In favour of this is the fact that vibration-induced tonic contraction employs the same motor units as the monosynaptic reflex (Lance *et al.* 1966). For motoneurones to be active in the production of tonic contraction while unable to respond to monosynaptic excitation, the inhibitory process responsible for the latter is likely to be presynaptic in nature.

This hypothesis was verified in a number of ways. The excitability of motoneurones was tested by direct stimulation and found to be normal during vibration, while the monosynaptic reflex was profoundly depressed. During vibration, a DRP was recorded which was conducted electrotonically along dorsal root filaments and was typical of the DRP associated with presynaptic inhibition (Eccles, 1964). In our experiments, the onset of the DRP closely resembled the time course of suppression of the monosynaptic reflex. The presynaptic nature of the inhibition was confirmed by the demonstration of primary afferent depolarization of group I afferent fibres during vibration. Augmentation of the antidromic volley was evoked by stimulation 3.5 mm deep to the dorsal root entry zone, indicating that group Ia afferents were depolarized. Finally, both DRP and reflex suppression were abolished by picrotoxin, an agent known to block presynaptic inhibition (Eccles, Schmidt & Willis, 1963). It is of interest that in those animals in which no DRP could be obtained, the monosynaptic reflex was not suppressed by vibration. This situation occurred only at the end of an experiment, or after episodes of hypoxia or hyperpyrexia and was attributed to deterioration of the preparation.

Vibration of muscle spindles resembles a stretch stimulus in its effect on Group Ia endings. Hunt (1952) reported that stretch reduces the size of the MSR in cats, and Devanandan, Eccles & Yokota (1965*a, b*) have shown that this effect depends upon presynaptic inhibition. Intravenous succinylcholine stimulates muscle spindle afferents and suppresses flexor and extensor monosynaptic reflexes by presynaptic inhibition (Cook, Neilson & Brookhart, 1965). Decandia, Provini & Táboříková (1967) have shown that the suppression of reflex discharge of spinal motoneurones by repetitive stimulation of group I afferent fibres is caused by presynaptic inhibition.

Presynaptic inhibition could account for the different effects of vibration on tonic and phasic reflexes. A synchronous Ia afferent volley would produce an excitatory post-synaptic potential (EPSP) subthreshold for activation of many motoneurones and thus the monosynaptic reflex would be inhibited, while repetitive Ia afferent volleys evoked by continuous vibration could lead to temporal summation of reduced EPSPs, activating

sufficient motoneurons to produce a tonic contraction of muscle. An alternative explanation is that tonic contraction, which depends upon supraspinal structures, employs a long reflex loop which could excite motoneurons while the input from Ia afferent fibres was impaired by presynaptic inhibition.

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