Muscle Spindle and Stretch Reflexes.

Main Contents.

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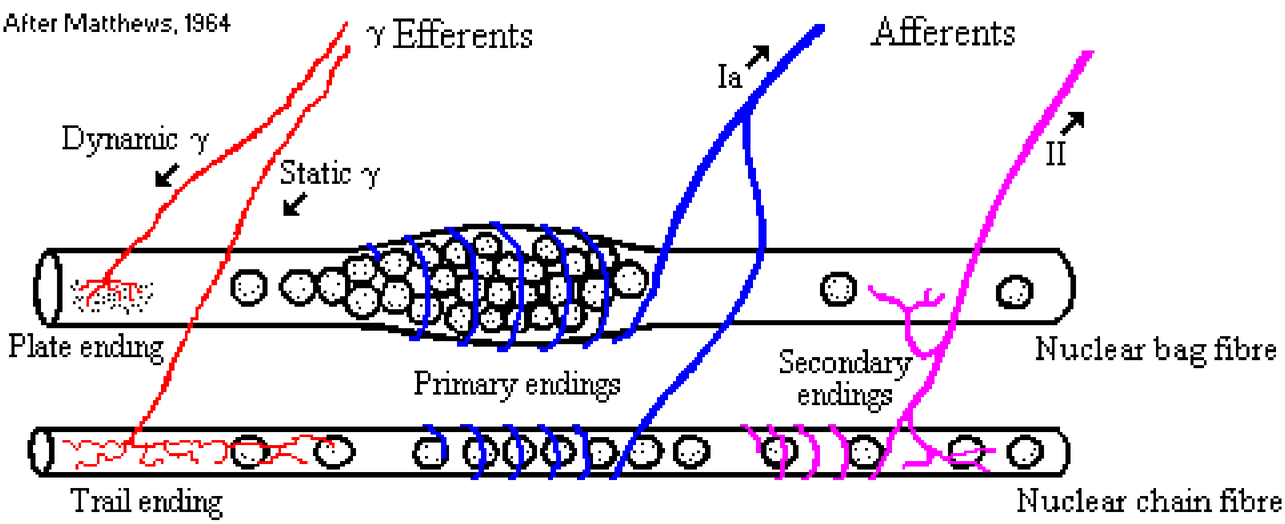
Muscle Spindle Basics.

Muscle spindles are found within the belly of muscles and run in parallel with the main muscle fibres.The spindle senses muscle length and changes in length. It has sensory nerve terminals whose discharge rate increases as the sensory ending is stretched. This nerve terminal is known as the **ANNULOSPIRAL** ending, so named because it is composed of a set of rings in a spiral configuration. These terminals (shown in blue) are wrapped around specialised muscle fibres that belongs to the muscle spindle **(INTRAFUSAL FIBRES)** and are quite separate from the fibres that make up the bulk of the muscle **(EXTRAFUSAL FIBRES)**.



There are two main types of intrafusal fibre .. **NUCLEAR BAG** and **NUCLEAR CHAIN** . For now we will stay with the Nuclear bag fibre .. so called because there is a bunch of about 100 nuclei in the central (or equatorial) region underlying the sensory nerve ending.

Another important feature.... a motor supply to the intrafusal muscle (shown above in red). In this region on either side of the central area the intrafusal fibres are able to contract if their motor supply is active. The motor supply comes via efferent fibres that usually fall into the gamma classification of diameters. They are often (and better) referred to as **FUSIMOTOR** fibres.

Two things can, in principle, cause the annulospiral ending to be stretched and so increase its discharge.

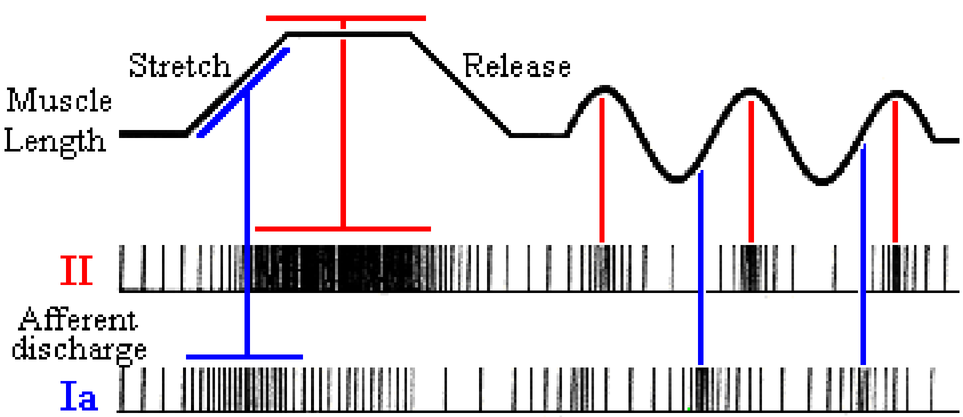
1. **A stretch of the muscle as a whole will stretch the spindles within it , and thus the sensory endings**.

2. **Fusimotor activity will cause contraction of the intrafusal fibres below the fusimotor nerve terminals either side of the central region. This will result in stretch of the central sensory region .**

Nuclear chain fibre also have annulospiral sensory endings in the central region (the nuclei are in line). It is a shared branch of the axon that supplied the central area of the nuclear chain fibre. This sensory nerve is of group **Ia**, the fastest found in the body.

Further out we see that there are other sensory endings, more closely associated with the chain fibres. These fall into the slower group **II** division of sensory nerves and are referred to as **SECONDARY** endings in contrast to the centrally located **PRIMARY** endings.

The two types of intrafusal fibre, (bag and chain) have different mechanical properties, and respond differently to their largely separate fusimotor fibres. They also differ in respect to their sensory endings. Consequently, the information relayed to the **CNS** by the spindle via group Ia and group II sensory endings is different.



In simple terms, the Ia afferents respond partly to muscle length, but respond more powerfully to changes in length (BLUE). The group II afferents are much better at registering length alone (RED).

Ia afferents can powerfully excite the **ALPHA MOTONEURONES** of the muscle containing the spindle. This is the basis of the classical **STRETCH REFLEX** in which extension of the muscle (and thus its spindles) cause a reflex contraction.

The spindle can therefore register muscle length and velocity. Furthermore the sensitivity to both length and velocity can be altered by the CNS via activity in the fusimotor system, the static gamma system controlling length sensitivity and the dynamic gamma system controlling velocity sensitivity.

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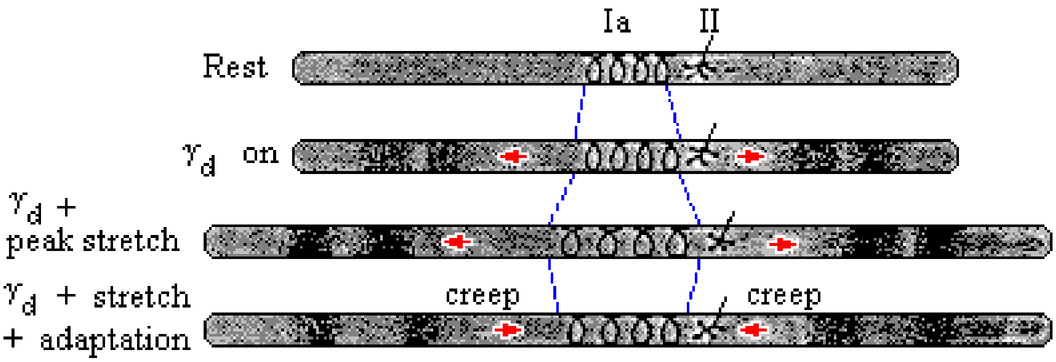
Last modified 15/1/96

Dynamic Bag 1 Fibre Response.



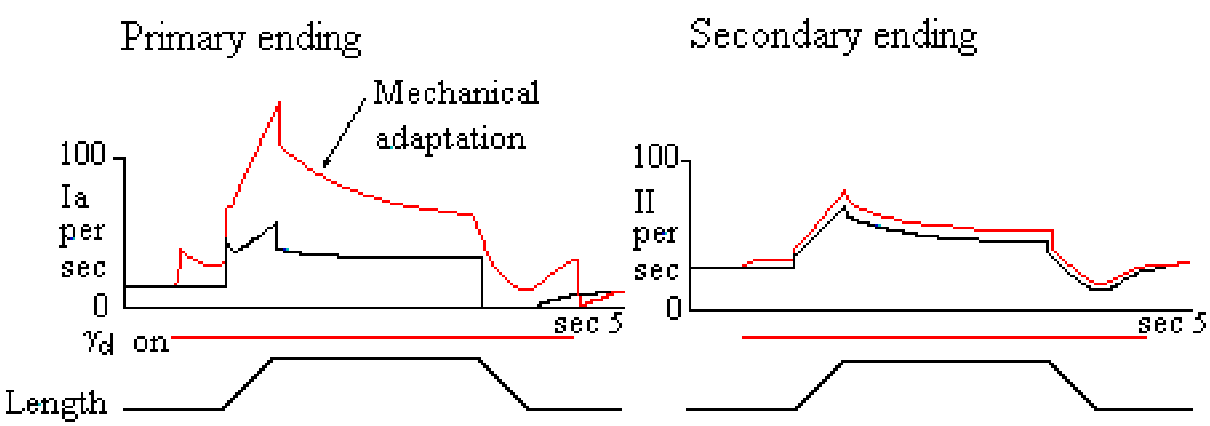
From resting conditions....

Dynamic fusimotor stimulation causes local intrafusal contraction which stiffens the polar regions, but has little effect on the primary region.

Much of the external stretch is transmitted to the primary region which may extend by 15%.

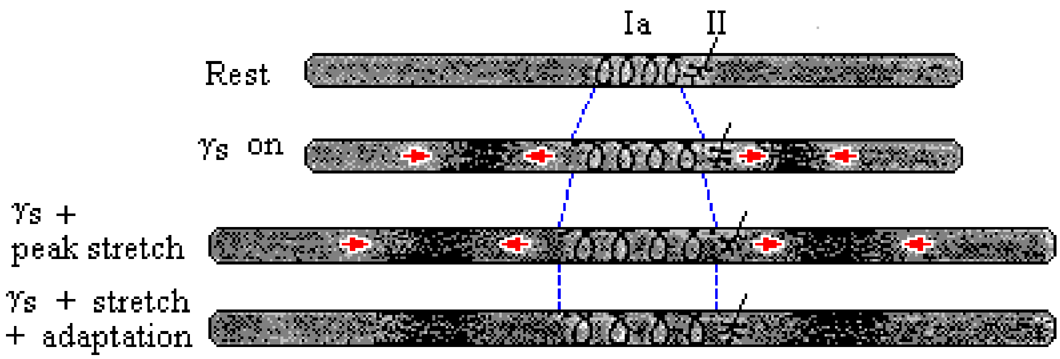
When stretch is maintained the polar regions 'creep' and the primary endings unload slightly. This is the basis of slow mechanical adaptation.

Dynamic bag fibres are sensitive to change in length and this is enhanced by dynamic fusimotor stimulation. Secondary afferents are rather less important.



Primary ending (group Ia) and secondary ending (group II) afferent discharge frequency during stretch alone (black lines) and during stretch superimposed on tonic dynamic fusimotor stimulation (red lines) at 75Hz.

Static Bag 2 Fibre Response.

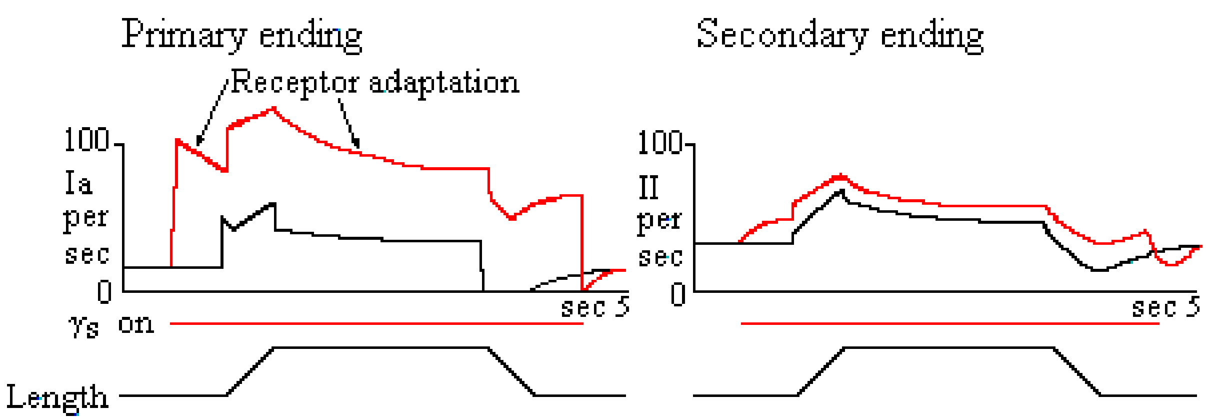


From resting conditions Static fusimotor stimulation causes intrafusal contraction which imposes a significant stretch on the primary ending, which may extend by up to 20%.

Much of the external stretch is taken up at the polar regions, and the primary region may only extend by 5%.

When stretch is maintained there is no further mechanical change, however there is a reduction in afferent discharge due to electrical adaptation.

Static bag fibres provide a strong positive bias to primary endings whilst reducing sensitivity to length changes. Effects on secondaries are similar but smaller.



Primary ending (group Ia) and secondary ending (group II) afferent discharge frequency during stretch alone (black lines) and during stretch superimposed on tonic static gamma fusimotor stimulation (red lines) at 75Hz.

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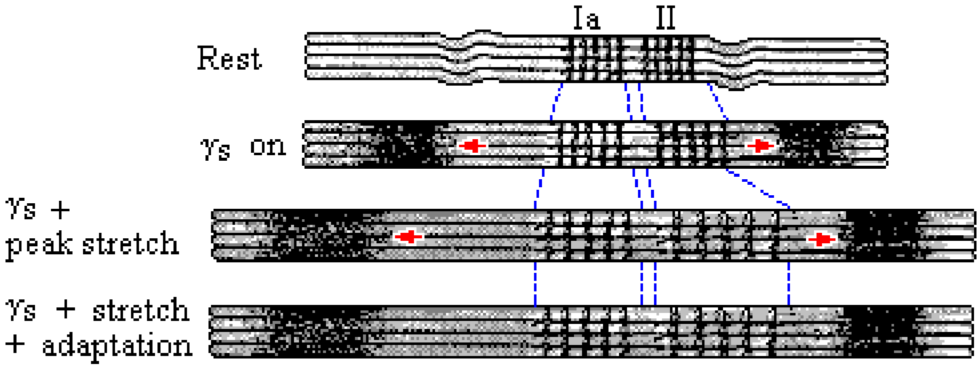
Nuclear Chain Fibre Response.



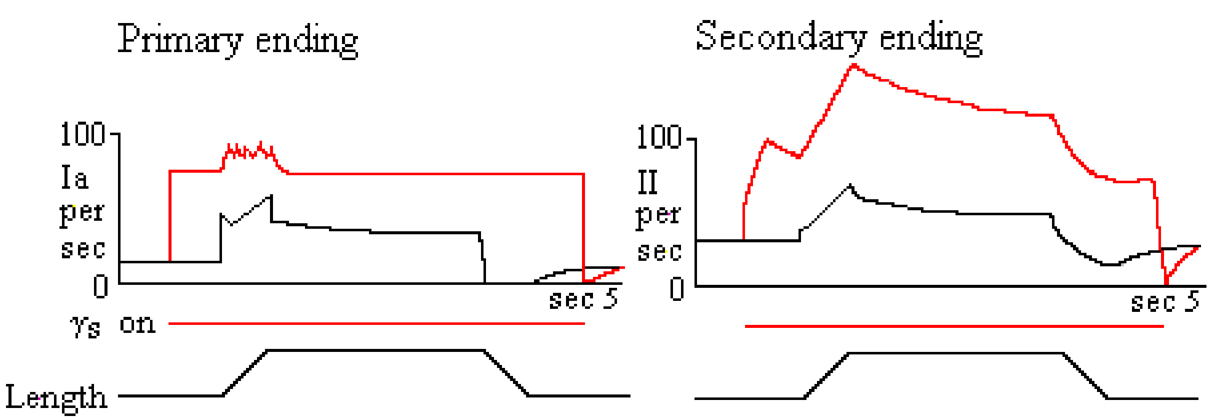
At resting conditions chain fibres are often kinked in the absence of fusimotor stimulation or external stretch.

Static fusimotor stimulation causes both primary and secondary endings to be stretched and increase discharge.

Stretching the chain fibres overall results in transmission of stretch to the primaries and, more so, to the secondaries which increase their discharge much more.

When stretch is maintained there is no further mechanical change, however there is a reduction in afferent discharge due to electrical adaptation.

Chain fibres bias the discharge of primary and secondary endings, disrupt length sensitivity of the primaries and ENHANCE length sensitivity of secondaries.



Primary ending (group Ia) and secondary ending (group II) afferent discharge frequency during stretch alone (black lines) and during stretch superimposed on tonic static gamma fusimotor stimulation (red lines) at 75Hz.

Innervaton.

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Sensory Innervaton.

Each spindle has one primary sensory ending .. spiral or annular (ring) terminations of a Group Ia afferent nerve which encircle all 3 types of intrafusal fibre.

Some spindles have no secondary sensory endings at all.. others have up to 5 (2 on one side 3 on the other side of the primary ending. Commonly find one primary (P) with one secondary ending adjacent (S1). Can have a further secondary ending(s) further out (S2 position) and there may be functional significance in S1 and S2 positions. Secondary endings are irregular spirals to chain fibres. S1 secondaries may have spray endings on Sb2 and Db1 fibres also.

All 3 intrafusal fibres contribute to Group Ia input.

Mainly chain fibres contribute to Group II input.

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Motor Innervaton.

2 types of fusimotor innervation from gamma motoneurones in the spinal cord... dynamic and static (originally named on the basis of their effects of Ia afferent discharge during muscle stretch).

Dynamic gamma axons innervate Db1 fibres at one or both poles by means of indented plate endings. Together they constitute the 'dynamic intrafusal system'.

The Sb2 is innervated by static gamma axons which generally form trail endings superficially on the fibres.

Chain fibres have a complex motor innervation. They receive static gamma axons with a variety of terminal morphologies.

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Functional Aspects of Muscle Spindles.

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Effect of fusimotor stimulation on intrafusal fibres.

All 3 types of fibre respond to fusimotor activity with graded contractions localised to the more polar regions. This causes the equatorial sensory region to be stretched.

Chain fibres have (limited) propagated action potentials, high fusion frequency, high fusimotor frequency and can excite primary ending mechanically.

Bag fibres have non-propagated responses, low fusion frequency and low fusimotor frequency.

Static bag 2. Local contraction occurs under the fusimotor end plates, causing the convergence of the unstimulated regions either side. The more polar parts are braced by large elastic fibres, so most extension is in the central 2mm of the fibre. Primary ending extended 10-25%, with corresponding increase in afferent discharge up to 100Hz (Sb2 discharge acts as pacemaker for the primary sensory discharge of the whole spindle). Peak frequency discharge falls (adapts) despite spiral remaining at same level of extension.

Dynamic bag 1. These fibres are quite different. Local contractions occur under the motor plates, but contraction also occurs at the poles (extracapsular area) where there are no plates. Mechanism not understood..not propagation of action potentials. Fibre is seen to move outwards at the end of capsular sleeve, but contraction is small and slow so primary ending is extended by 2-8% only. Small rise in Ia afferent discharge. Adaptation therefore less evident. Effect on secondaries is negligible. Functional driving frequency 25-75 Hz.

Nuclear Chain Fibres. Most change in activity when driven 50-150Hz. Limited action potential propagation, so localised contraction in capsular sleeve region. These contractions are brief, so primaries are mechanically excited and follow the stimulation frequency 1:1 up to 75 Hz. .. as frequency rises Ia discharge is driven 1:2 or 1:3 then irregular (despite fact that chain fibre primaries may be extended up to 20%. Powerful secondary excitation, with pronounced adaptation.Chain fibres thus powerfully contribute to primary and secondary response to fusimotor stimulation.

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Effect of Stretch on spindle sensory discharges.

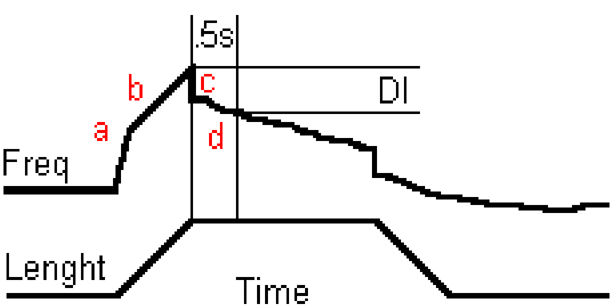
To simplify first consider all intrafusal fibres inactive, i.e. no fusimotor input (passive spindle).

Consider ramp stretch, hold, ramp unstretch.

Primary endings discharge at high frequency during stretch and fall silent during release Secondary endings have less marked increase in discharge during stretch and continue to fire during release. Both show a linear rise in discharge frequency during the stretch .. represented by an offset straight line. Offset and slope depend on velocity of stretch. Response is proportional to product of a length term and velocity term ($l \times v^{.3}$). Slope of response during stretch gives measure of length sensitivity under dynamic conditions. Difference between initial and final adapted frequencies indicates length sensitivity under static conditions. Fusimotor activity modifies dynamic and static length sensitivities, not velocity sensitivity.

Right at the start of a stretch there is a brief rapid discharge (a similar rapid fall at end of stretch). This effect is more noticeable in primaries. Usually attributed to stiction.

During the plateau of applied stretch there is adaptation lasting several seconds. The discharge falls with maintained stretch. This effect is very small in most primaries, and is due to mechanical creep in Db1 fibre. The more pronounces slow adaptation in secondaries is probably ionic in origin.



'Dynamic index' .. The fall in discharge frequency in the first 0.5 sec following the completion of a ramp stretch. Several factors contribute: Peak discharge freq. depends on amplitude of initial fast rise phase (a) and the slope of the response during stretch (b), the amplitude of the fast fall phase (c) and the slow adaptation of whatever origin (d).

a and c may have an ionic basis. b is explained mechanically.

Primaries are uniquely non-linear ... may be 100x more sensitive to small stretches than large ones.

Afferent responses to stretch during fusimotor activity.

Large ramp on Primary and Secondary endings during max activation of Db1 and Sb2 and chain fibres compared.

When a Db1 fibre is activated by a dynamic gamma axon there is little extension of primary ending but the stiffness of the contracting capsular sleeve and extracapsular regions is enhanced so that more applied stretch reaches spiral .. i.e. Ia discharge is increased. When held at a new length there is creep which is the basis of the considerable mechanical adaptation resulting in an adapted discharge that is not greatly different to the situation of no fusimotor input. Fusimotor activity in the Db1 fibre greatly increases the sensitivity of the primary ending to length changes during movement. Secondaries if present will experience a similar effect but to a lesser extent.

Stretch of active Sb2 fibres has a negligible effect on primary spiral, which is already greatly extended by the static fusimotor activity alone. Much of the stretch seems to be accommodated by the extracapsular region. Fusimotor activity in the Sb2 fibre greatly increases the discharge of the primary ending whilst reducing its sensitivity to static and dynamic length changes. (to put it another way, big DC offset but reduced gain). Similar but smaller effects on secondaries which are appreciable in number.

Fusimotor activity in chain fibres applies a large positive bias to the discharge of both primary and secondary endings. Static and dynamic length sensitivity of primaries is disrupted, that of secondaries is enhanced.

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Stretch Reflexes.

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Tendon jerk and tonic stretch reflex.

Ia from primaries have powerful excitatory effect on a motoneurones of same muscle and synergists in adjacent spinal segments. May be monosynaptic or polysynaptic. Ia also inhibit a motoneurones of antagonistic muscles via inhibitory interneurone and corresponding contralateral muscles. Ia afferents also have a weak polysynaptic excitatory action on dynamic and static gamma motoneurones.

Group II afferents from spindle secondaries also excite autogenic alpha motoneurones via mono & polysynaptic paths. Monosynaptic component involves about 50% of the motoneurones that are excited by Ia gamma motoneurones. highly responsive to elect stim of group II afferents (but not clear how much of this group II input is purely spindle in origin).

Classical stretch reflex 'the capacity of a muscle to resist extension' is sum of these spindle projections to muscle. The monosynaptic Ia component is responsible for the 'tendon jerk' . The 'tonic stretch reflex' is mainly disynaptic or polysynaptic.

Monosynaptic component thought to be unaffected by supraspinal inhibition (no interneurone for synaptic modification to occur), but presynaptic inhibition is possible. Reflex tension produced by maintained stretch depends on excitation from Ia and II afferents and autogenic inhibition from Ib tendon afferents. Ib are weakly autogenically inhibitory to gamma motoneurones, especially dynamic gamma motoneurones. Tonic stretch reflex also very dependent on supraspinal input to associated interneurones and so only operate when CNS 'wishes them to do so'.

Added to this must be a consideration of the mechanical properties of muscle.. length/tension relationship, although physiologically the muscle is always near optimum.

Spinal interneurones are an important target for supraspinal control and gating of reflexes, e.g. in walking cycle.

Renshaw cells may be an important stabilising factor on a and spinal interneurones as well as gamma motoneurones.

The monosynaptic reflex in man.

H reflex. Stimulate nerve to leg muscle and record EMG. As strength increases a muscle response with monosynaptic latency is obtained (Hoffman or H reflex) due to excitation of some Ia afferents. Then as strength is increased, get a direct motor response from activated a motoneurones (M response) whilst H reaches a maximum. M wave increases further as motoneurones are recruited but H gets smaller and eventually disappears as antidromic invasion of the motoneurones renders the cell bodies refractory.

Jenddrassik manoeuvre. Tendon jerk is reinforced by clenching fists or jaw. Gamma pathway is centrally facilitated rendering spindle more sensitive to stretch.

Silent period. During a maintained voluntary contraction apply a maximal shock to a muscle nerve. Get a direct excitation in EMG followed by a silent period (80ms in human adductor pollicis). During the silent period the muscle is in tension above the voluntary level and the spindles are unloaded .. Ia discharge falls and reflex support of a motoneurones is lost. Longer latency human stretch reflexes.

Stretching relaxed or contracting muscles.

In a cat stretching a relaxed muscle produces a reflex development of tension with a large monosynaptic component. There is a background discharge in spindles at rest. In man this is less so and little reflex contraction in resting muscle. In contracting muscle however there is a powerful tonic stretch reflex. There is a monosynaptic component (M1) but functionally most of the response is at longer latency (M2). This could come from group Ia or group II inputs via polysynaptic spinal pathways (as shown for group II) or via higher centres, even cortex. Voluntary responses (M3) are at even longer latencies.

Gain of tonic stretch reflex in man varies with load (or rather force developed by muscle). Hence at strong voluntary contraction levels, large reflex tensions can also be developed.

Central Control of Dynamic & Static Fusimotor Neurones. Dynamic and Static fusimotor neurones are under separate central control. Fusimotor activity can be modified by stimulation of many areas of the CNS. Dynamic responsiveness of primaries greatly reduced by repetitive stimulation of anterior cerebellum.

There are separate corticospinal dynamic and static fusimotor pathways (differential respose to anaesthesia). Varying cortical stimulation strength recruits in order Sb2, chain, Db1 but all respond less than in normal function.

Motor Control Pathways to Alpha and Gamma Motoneurones.

Contents.

Follow-up length servo hypothesis.

Proposed that movement could be produced by the 'indirect route' .. Gamma motoneurones, fusimotor contraction, increased spindle afferent discharge, reflex alpha activity, contraction, unloading of spindle to bring discharge back to original level. Fitted in with the silent period observations.

Nice idea but unfortunately untenable because gain too low. Also alpha precedes Ia discharge.

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Alpha-Gamma linkage, co-activation or indepenence?

Evidence has been obtained to establish that co-activation happens.(alpha-gamma linkage implies a more rigid relationship, alpha-gamma independence implies a lack of correlation).

We do not know anything about the time course and intensity of fusimotor outflow in human movements but can state that alpha and gamma are active at the same time. There is no evidence for a rigidly fixed relationship. We therefore talk about alpha-gamma co-activation with indepenence under some circumstances. The same is probably true in monkeys and cat.

Integration at alpha and gamma motoneurone pools. We are used to the ideas leading to the concept of the 'final common path' for alpha motoneurones. The same concepts might well apply to gamma motoneurone pools .. 'the final common input'. The inputs to fusimotor neurones include: group II , III and IV from muscle (converging mainly on static) and skin afferents (influencing dynamic).

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The Role of Muscle Spindles in Posture and Movement.

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Servo assistance of the motor command.

EMG evidence and the M2 response establish this role. A motor command via the alpha motoneeurones can only be effective in the presence of adequate facilitation from spindles etc. If alpha activation leads to muscle shortening then the unloading of the spindle will reduce alpha motoneurone activity unless spindle afferent output is maintained by fusimotor activity.

Adjustment of spindle bias during movement.

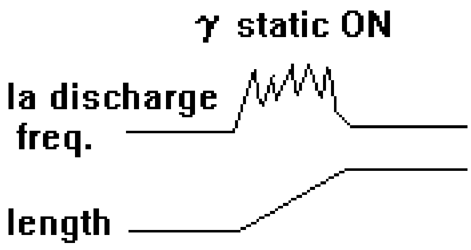
Logical way to maintain or increase spindle input (to alpha motonurones) is to drive Sb2 fibre via static gamma system. This biasses Ia output. Db1 fibre biassing action too small for use except in small slow movements. Appropriate action is therefore co-activation of alpha and gamma with the gamma recieving a modulated pattern based on the alpha pattern. As muscle shortens Ia discharge is maintained. This explains the lack of change in Ia output seen in human movement.

Compensation for spindle unloading could also come from group II pathway by increasing static fusimotor output to chain fibres with secondary ending. Powerful biassing action in this context.

Note that the above conditions keep the spindle responsive to unexpected length changes resulting from fatigue, change in load or obstruction of movement.

Abolition of spindle length sensitivity during movement.

This is quite different from the above. Static fusimotor activation of chain fibres (up to 75Hz) makes then insensitive to length changes. Remember that some static gamma axons go to Sb2 and to chain fibres. Action on Sb2 potentiates the driving action of chain fibres on the primary ending. So.. tonic static fusimotor drive could hold Ia afferent discharge more or less constant during muscle shortening without the need for modulation based on alpha drive. What can be observed is a rather irregular group Ia afferent discharge that is largely unaffected by muscle length.



This can be demonstrated to occur during low velocity normal unobstructed movements. At higher velocities the length sensitivity if the primary ending is apparent, perhaps due to the input from Db1 fibres during rapid length changes dominating the Ia discharge.

Modulation of spindle length sensitivity during movement.

Dynamic intrafusal system enhances the dynamic sensitivity of the primary ending during movement. A high sensitivity to length changes is precisely what is required during movement if deviations from a desired trajectory are to be rapidly corrected. During imposed movements in conscious cats very hight Ia afferent discharges occur. This probably reflects a combination of dynamic and static fusimotor activity. The Db1 effect directly increases dynamic length sensitivity, and the Sb2 can also increase the dynamic responsiveness of the spindle either directly by increasing the dynamic sensitivity of the secondary endings (group II afferent input), or indirectly by biasing group II discharge, so causing reflex facilitation of dynamic fusimotor neurons.

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Modelling of planned movements.

2 messages required.

1. A message to the spindle signalling the desired trajectory of movement.

2. A signal to extrafusal muscle that takes into account any load and fatigue. If the load proved unexpectedly great then the spindle would suffer a smaller degree of unloading, afferent discharge would

increase and movement would be reflexly assisted. The discharge may also cause a central command to increase motor outflow. This is basically the alpha - gamma coactivation principle.

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Muscle tone and rigidity.

Low frequency spontaneous acivity in Sb2 fibres applies a modest bias to Ia afferent discharge which in turn leads reflexly to a modest contraction - aiding muscle tone. An increase in static g output to Sb2 fibres would result in increased muscle tone via group Ia pathway. An increase in static g output to the chain fibres would increase muscle tone via Ia and II pathways. Hypertonicity could be the result of over-activity in either of these static intrafusal systems. We do not at present know the relative extent of their involvement or interdependence.

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Conscious appreciation of position.

Spindles contribute to propriception (sense of postion) and possibly kinaesthesia (sense of movement). Vibration, which selectively excites primaries causes large position errors in a blindfolded subject. Sense of position is not lost, but the length signal is wrongly calibrated. The secondary sensory endings provide a much better length signal than the primary ending.

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Muscle Spindle MCQ's.

Here are 3 MCQ's to test your knowledge.

---

1. The frequency of discharge from muscle spindle primary endings:

A: increases if the muscle is stretched.

○ True ○ False ◉ Don't Know

B: increases if the antagonist muscle shortens.

○ True ○ False ◉ Don't Know

C: is related to the rate of stretch.

○ True ○ False ◉ Don't Know

D: is increased if there is fusimotor activity.

○ True ○ False ◉ Don't Know

E: is increased by activity in Group Ib afferent fibres.

○ True ○ False ◉ Don't Know

---

2. Mammalian Muscle Spindles:

A: have monosynaptic connections with motoneurones.

○ True ○ False ◉ Don't Know

B: are stimulated by extrafusal muscle contractions.

○ True ○ False ◉ Don't Know

C: receive skeletal fusimotor (beta) innervation in some cases.

○ True ○ False ◉ Don't Know

D: send information to the cerebral cortex.

○ True ○ False ◉ Don't Know

E: contribute to the postural tone of surrounding muscles.

○ True ○ False ◉ Don't Know

---

3. Immediately following section of the dorsal and ventral roots supplying a muscle, an increase in the frequency of discharge of a spindle primary afferent fibre from that muscle will be produced by:

A: passive stretching of the muscle.

○ True ○ False ◉ Don't Know

B: stimulation of the alpha motoneurones to the muscle distal to the section.

○ True ○ False ◉ Don't Know

C: stimulation of the fusimotor fibres to the muscle distal to the section.

○ True ○ False ◉ Don't Know

D: contraction of a synergistic muscle.

○ True ○ False ◉ Don't Know

E: strong electrical stimulation of the proximal end of the cut dorsal root.

○ True ○ False ◉ Don't Know

Reset Submit

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Muscle Spindle MCQ's.

Here are your results for the 3 MCQ questions.

---

1. The frequency of discharge from muscle spindle primary endings:
A: increases if the muscle is stretched.
You answered Don't Know. The correct answer is True.
The stretch of the muscle (extrafusal fibres) is imposed on the spindle and the stretched primary endings in the equatorial region increase their discharge as a consequence.

B: increases if the antagonist muscle shortens.
You answered Don't Know. The correct answer is True.
Antagonist shortening occurs when the agonist (in which the spindle lies) lengthens as in A.

C: is related to the rate of stretch.
You answered Don't Know. The correct answer is True.
The primaries are senstive not only to absolute length but also rate of change of length.

D: is increased if there is fusimotor activity.
You answered Don't Know. The correct answer is True.
Fusimotor activity contracts the polar regions on either side of the equatorial region in which the primaries lie. The latter thus experience a pull from either end and so increase their discharge.

E: is increased by activity in Group Ib afferent fibres.
You answered Don't Know. The correct answer is False.
There is no direct connection between Ib fibres and spindle primaries.

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2. Mammalian Muscle Spindles:
A: have monosynaptic connections with motoneurones.
You answered Don't Know. The correct answer is True.
The simplest example of a reflex such as the knee jerk.

B: are stimulated by extrafusal muscle contractions.
You answered Don't Know. The correct answer is False.
This would tend to unload the spindle and reduce discharge.

C: receive skeletal fusimotor (beta) innervation in some cases.
You answered Don't Know. The correct answer is True.
But it is much more common in non-mammalian species.

D: send information to the cerebral cortex.
You answered Don't Know. The correct answer is True.

This is the basis of the long loop reflex.

E: contribute to the postural tone of surrounding muscles.
You answered Don't Know. The correct answer is True.
Spindles provide an important input to alpha motoneurones to influence their excitability in postural activity.

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3. Immediately following section of the dorsal and ventral roots supplying a muscle, an increase in the frequency of discharge of a spindle primary afferent fibre from that muscle will be produced by:
A: passive stretching of the muscle.
You answered Don't Know. The correct answer is True.
This will stretch the spindles in it and hence their primary afferents.

B: stimulation of the alpha motoneurones to the muscle distal to the section.
You answered Don't Know. The correct answer is False.
The extrafusal fibres will contract, shortening the muscle and unloading the spindle.

C: stimulation of the fusimotor fibres to the muscle distal to the section.
You answered Don't Know. The correct answer is True.
The intrafusal fibres will contract and impose a stretch on the primaries located at the equator.

D: contraction of a synergistic muscle.
You answered Don't Know. The correct answer is False.
No reflex activity can reach the muscle and influence it or its afferents.

E: strong electrical stimulation of the proximal end of the cut dorsal root.
You answered Don't Know. The correct answer is False.
Although this will excite the motoneurones in the ventral horn they are cut off from the muscle and cannot influence it.

Your score
0 out of 15

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