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Classic picture of muscle spindle as seen by Ruffini in From Matthews Figure 3. Responses shown in both presence and absence of tonic fusimotor activity of decerebrate cat. Bottom, responses of endings when deafferented by ventral root V. Top, responses of the same endings when ventral roots were intact and were tonically biased by spontaneous fusimotor activity. From Matthews Figure 4. From Matthews Figure 5. Effect of increasing the velocity of stretching on the initial burst given by a primary ending at beginning of stretch and on the more prolonged velocity response. Time calibration applies only to the static phases of the response; dynamic phases are on slightly expanded time scales, which may be deduced from the parameters of stretching. From Matthews Figure 6. Comparison of the sensitivity to sinusoidal stretching within the linear range of a primary and a secondary ending studied together over a wide range of frequencies of stretching measured in cycles per second Hz. The sensitivity at any frequency is defined as the amplitude of the afferent response, considered as a sinusoidal modulation of firing measured in impulses per second divided by the amplitude of stretching measured in millimeters. The endings were being tonically biased by the spontaneous fusimotor activity of the decerebrate cat. The continuous lines represent the vector sum of responses to the length component of the stimulus dominant for the horizontal portion at low frequencies and to the velocity component dominant for the diagonal portion of the line at high frequencies. The same curve transposed vertically approximately fits both endings over a considerable region. This shows that in the linear range they differ in their absolute sensitivity, rather than in the ratio of their length to their velocity sensitivity. From Matthews and Stein Figure 7. Soleus muscle of decerebrate cat contracting in response to stimulation of contralateral peroneal nerve. Physiological manifestation of a high sensitivity of primary ending, but not of secondary ending, to small stretches. Sensitivity of primary ending is demonstrated by the fact that both of the 2 primary endings can be seen to respond in synchrony to the small irregularities occurring in a reflexly induced muscle contraction, which occurred under approximately isotonic conditions. Discharges of the 3 afferents were recorded simultaneously. From Matthews Figure 8. Records of instantaneous frequency, a, in absence of fusimotor stimulation; b, during repetitive static axon stimulation; c, during repetitive dynamic axon stimulation. Time scale expanded during dynamic phase of stretch. From Brown and Matthews Figure 9. Each axon stimulated at several frequencies to show effect on responsiveness of a primary ending to a ramp stretch as the balance between them is shifted. Dotted line from static axon to bag1 fiber represents the chief matter of current controversy. Drawing of the way in which a sole surviving static axon following degeneration of the rest of the motor innervation in cat was seen to distribute itself between a bag fiber and 2 chain fibers. From Barker et al. Each horizontal row represents a spindle, with its several intrafusal muscle fibers shown by circles. Presence of glycogen is shown by solid circle, and its depletion following neural activation of the fiber is shown by open circle. The bag fibers were not then subdivided. Rearranged from Brown and Butler Figure Recent examples that glycogen depletion, after stimulation of single dynamic axons, is restricted to bag1 intrafusal fibers. Each row represents a spindle with its intrafusal muscle fibers shown by circles. Solid circle, glycogen presence; open circle, glycogen depletion. Adapted from Barker et al. Diagrammatic representation of the particular intrafusal muscle fibers that were seen to contract by Boyd and his colleagues in isolated spindles after stimulation of single fusimotor axons. Each row represents a spindle and each symbol represents an intrafusal muscle fiber that was seen to move with fusimotor stimulation. The symbol is varied with the type of axon that was found to activate the fiber in question. When a given axon influenced 2 different types of intrafusal fiber the symbols are joined by a horizontal line. It may be seen that a bag fiber influenced by a dynamic axon dynamic nuclear bag was never influenced by a static axon or in combination with a chain fiber, but that other bag fibers were activated by static axons static nuclear bag and

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that this was commonly in conjunction with chain activation. Adapted from Boyd et al. Motor innervation of spindle as described by Boyd et al. Redrawn from Boyd et al. Recent examples of varied patterns of glycogen depletion involving all 3 types of intrafusal fiber seen when single static axons are stimulated. Position response of a primary ending as seen during dynamic stretching, assuming that length and velocity components of response are approximately additive. Redrawn from Crowe and Matthews Figure Dynamic index is difference between frequency of discharge just before end of dynamic phase of a ramp stretch and that occurring 0. From Crowe and Matthews Figure Change induced by fusimotor stimulation in responsiveness of spindle primary ending to small amplitude sinusoidal stretching of a wide range of frequencies. Top, logarithmic plots of ratio of sensitivity of activated spindle cf. Bottom, linear plots of arithmetic difference between the phases in the 2 states. For motor control purposes, only the effects below 20–30 Hz appear relevant. At each frequency the amplitude of stretching was restricted to the linear range. From Goodwin, Hulliger, and Matthews Figure Effect of fusimotor stimulation on response of a primary ending to sinusoidal stretching of appreciable amplitude 1 mm peak to peak at 3 Hz. Discharge in the human of a presumed primary spindle afferent during a weak, voluntary isometric contraction of the muscle it supplied flexor of index finger. From Vallbo Figure Responses of a presumed spindle primary afferent from a jaw closing muscle of conscious cat. From Cody et al. Example of a period of movement in the conscious cat. Degree of fusimotor activity was such that the discharge of a presumed spindle primary afferent remained approximately constant. Behavior of a presumed primary spindle afferent in the human during slow rhythmic voluntary movement. Spindle lay in the tibialis anterior. Top, instantaneous frequency of firing; bottom, ankle movement. From Burke et al. Intramuscular branching of fusimotor fibres. Dynamic characteristics of Golgi tendon organs. Response characteristics of muscle spindle endings at constant length to variations in fusimotor activation. Some observations on the efferent innervation of rat soleus muscle spindles. The division of control of muscle spindles between fusimotor and mixed skeletomotor fibres in a rat caudal muscle. Identification of a descending system for control of dynamic sensitivity of muscle spindles. Histological analysis of muscle spindles following direct observation of effects of stimulating dynamic and static motor axons. Intrafusal branching and distribution of primary and secondary afferents. The innervation of the muscle spindle. Symposium on Muscle Receptors. The morphology of muscle receptors. Handbook of Sensory Physiology. Muscle Receptors, edited by C. Identification of intrafusal muscle fibres activated by single fusimotor axons and injected with fluorescent dye in cat tenuissimus spindles. Morphological identification and intrafusal distribution of the endings of static fusimotor axons in the cat. The motor innervation of cat and rabbit muscle spindles. Rabbit intrafusal muscle fibres. Fusimotor innervation in the cat. Motor fibres innervating extrafusal and intrafusal muscle fibres in the cat. Frequencygrams of spindle primary endings elicited by stimulation of static and dynamic fusimotor fibres. Intracellular potentials from intrafusal muscle fibres evoked by stimulation of static and dynamic fusimotor axons in the cat. Cinematographic analysis of contractile events produced in intrafusal muscle fibres by stimulation of static and dynamic fusimotor axons. The response to vibration of the end organs of mammalian muscle spindles. The response of Golgi tendon organs to single motor unit contractions. The structure and innervation of the nuclear bag muscle fibres and the nuclear chain muscle fibre system in mammalian muscle spindles. The response of fast and slow nuclear bag fibres and nuclear chain fibres in isolated cat muscle spindles to fusimotor stimulation, and the effect of intrafusal contraction on the sensory endings. Control of dynamic and static nuclear bag fibres and nuclear chain fibres by gamma and beta axons in isolated cat muscle spindles. The contribution of intrafusal creep to the dynamic component of the Ia afferent discharge of isolated muscle spindles. Motor control of nuclear bag and nuclear chain intrafusal fibres in isolated living muscle spindles from the cat. Studies on the site of termination of static and dynamic fusimotor fibres within muscle spindles of the tenuissimus muscle of the cat. An investigation into the site of termination of static gamma fibres within muscle spindles of the cat peroneus longus muscle. Observations on the fusimotor fibres of the tibialis posterior muscle of the cat.

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## Chapter 2 : CiteSeerX " Citation Query Mammalian Muscle Receptors and Their Central Actions

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Biewener, Peter Aerts, Anna N. Ahn, Z Hillel J. Daniel, A Robert J. Richard Nichols, Roger D. Satterlie, Brett Szymik " Synopsis Neuromechanics seeks to understand how muscles, sense organs, motor pattern generators, and brain interact to produce coordinated movement, not only in complex terrain but also when confronted with unexpected perturbations. Applications of neuromechanics include ameliorating human health problems including prosthesis design and restoration of movement following brain or spinal cord injury , as well as the design, actuation and control of mobile robots. In animals, coordinated movement emerges from the interplay among descending output from the central nervous system, sensory input from body and environment, muscle dynamics, and the emergent dynamics of the whole animal. The inevitable coupling between neural information processing and the emergent mechanical behavior of animals is a central theme of neuromechanics. Fundamentally, motor control involves a series of transformations of information, from brain and spinal cord to muscles to body, and back to brain. The control problem revolves around the specific transfer functions that describe each transformation. The transfer functions depend on the rules of organization and Spasticity and muscle contracture following stroke by N. Neilson, School Of , " A variety of studies suggest that spasticity is a distinct problem and separate from the loss of dexterity, but that it may be implicated in the formation of muscle contracture and even in the recovery of strength. In order to address these issues, we examined the relationship between spasticity, contracture, strength and dexterity in the affected upper limb following stroke. Spasticity was measured both as increased tonic stretch reflexes and increased resistance to passive stretch hyper-tonia. Twenty-four patients were recruited non-selectively from three rehabilitation units within 13 months of their stroke. Animal movement is immensely varied, from the simplest reflexive responses to the most complex, dexterous voluntary tasks. Here, we focus on the control of movement in mammals, including humans. First, the sensory inputs most closely implicated in controlling movement are reviewed, with a focus on somatosensory receptors. The response properties of the large muscle receptors are examined in detail. The role of sensory input in the control of movement is then discussed, with an emphasis on the control of locomotion. The interaction between central pattern generators and sensory input, in particular in relation to stretch reflexes, timing, and pattern forming neuronal networks is examined. It is proposed that neural signals related to bodily velocity form the basic descending command that controls locomotion through specific and well-characterized relationships between muscle activation, step cycle phase durations, and biomechanical outcomes. Sensory input is crucial in modulating both the timing and pattern forming parts of this mechanism. Show Context Citation Context In this view, spindle afferent firing should remain fairly constant unless unexpected length changes occur. Data emerged showing that spindle firing rates actually fluctuated significantly during mo

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## Chapter 3 : Chapter 11 - Muscle Receptors

*Mammalian muscle receptors and their central actions (Monographs of the Physiological Society, no. 23) [Peter B. C Matthews] on blog.quintoapp.com \*FREE\* shipping on qualifying offers.*

It is difficult to define the term in a way that includes everything we call a reflex, yet says anything that allows one to decide if any particular event is a reflex. We will follow suit in a sense and define a reflex as "a relatively stereotyped movement or response elicited by a stimulus applied to the periphery, transmitted to the central nervous system and then transmitted back out to the periphery. Most reflexes involve the simplest of neural circuits, some only two or a few neurons; but many, like the scratch-reflex in a dog, are so complicated that their organization remains a mystery. Most reflexes are "involuntary" in the sense that they occur without the person willing them to do so, but all of them can be brought under "voluntary" control. Some reflexes serve protective functions, like the eyeblink reflex. Some reflexes act as control systems to maintain homeostasis in some bodily systems. There are a number of ways of classifying reflexes. One is in terms of the systems that receive the stimulus and give the response. There are viscerovisceral reflexes, for example the decrease in heart rate that follows distention of the carotid sinus; viscerosomatic reflexes, like the abdominal cramping that accompanies rupture of the appendix; somatovisceral reflexes, such as the vasoconstriction that results from cooling the skin; and somatosomatic reflexes, like the knee jerk that follows tapping the patellar tendon. Reflexes can also be classified in terms of the number of neurons or synapses between the primary afferent neuron and the motor neuron. We distinguish two types, the monosynaptic reflex and the much more common multisynaptic or polysynaptic reflex. The term multisynaptic implies that more than one synapse is involved, whereas polysynaptic usually implies that the pathway is of variable length, some parts disynaptic, some trisynaptic, etc. The tendon jerk reflex Fig. The tendon jerk reflex. A circuit diagram of the elements of the tendon jerk reflex: Note that this is a monosynaptic reflex. F and E indicate flexor and extensor muscles. Amsterdam, Elsevier, The simplest reflex is the monosynaptic reflex or the two-neuron reflex, an example of which is the tendon jerk reflex or tendon tap reflex, sometimes called the myotatic reflex. This is the reflex that is elicited by tapping the tendon just below the patella. The tap, applied to the tendons of the quadriceps muscles, stretches the muscles and their muscle spindles. A brisk tap excites the group Ia afferent fibers, because of their velocity sensitivity, ultimately causing the muscle to contract. The neural circuit for this reflex is shown in Figure 1. The group Ia afferent neuron enters the spinal cord through the dorsal root, penetrates into the ventral horn, and then synapses on an alpha-motoneuron. This is the only synapse in the pathway within the spinal cord, thus the reflex is monosynaptic. The axon of the alpha-motoneuron then exits the spinal cord through the ventral root and innervates the extrafusal fibers of the muscle from which the group Ia afferent fiber originated, i. Note that the drawing shows only one neuron of each type, afferent and efferent, but that one represents many. For example, the cat soleus muscle contains about 50 group Ia afferent fibers and each soleus alpha-motoneuron appears to have a synaptic connection with each one of those 50 group Ia afferent fibers. A brief tap on the tendon will therefore activate many of the group Ia afferent fibers, producing contraction of many of the soleus muscle fibers. Tapping the tendon of the rectus femoris muscle of the quadriceps group produces a brief stretch of that muscle that acts as a powerful stimulus for the group Ia afferent fibers of the muscle, causing them to give a brief, synchronous discharge. Each discharge, after propagating down the group Ia axon to its termination, produces an EPSP in the rectus alpha-motoneurons. Because there are many EPSPs from many group Ia afferent fibers occurring nearly simultaneously in some alpha-motoneurons, the membrane potentials reach critical firing level by spatial summation with hypopolarization to spare, and the motoneurons discharge action potentials. The action potentials travel out by way of the ventral root to the muscle and, because the neuromuscular junction is an obligatory synapse, the muscle contracts. The contraction in turn causes the spindle to be unloaded or shortened passively, its equatorial region to relax, the group Ia afferent fiber to turn off, and the muscle to

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relax. This is the tendon jerk reflex. Many of the homonymous alpha-motoneurons are not discharged by the Ia afferent fiber input, but have EPSPs evoked in them that do not achieve the critical firing level. The excitability of the motoneuron is therefore increased. This group of excited neurons is called the subliminal fringe. The presence of the subliminal fringe accounts for enhancement of the reflex response under certain circumstances, for example with the Jendrassik maneuver. In the Jendrassik maneuver, the fingers of the two hands are locked together and one hand pulls against the other while the tendon tap reflex is evoked. The reflex evoked is stronger than in the absence of the maneuver. Interestingly, mental arithmetic and a number of other activities will do the same thing! During the Jendrassik maneuver activity, originating perhaps in the cervical enlargement of the spinal cord or some other rostral center, descends the spinal cord to excite alpha-motoneurons. This activity by itself does not cause the alpha-motoneurons to discharge or the muscle to contract, but when added to the subthreshold excitation of the subliminal fringe caused by the tap-induced muscle stretch, it causes the neurons in the subliminal fringe to discharge. The reflex contraction will therefore be larger than normal. There may also be some influence of increased gamma-motoneuron activity, increasing the sensitivity of the primary spindle endings, but this influence should be small because the stimulus for the reflex is very brief. The value of the stretch reflex mechanism may not be clear at first, but some reflection may clarify its role in motor control. It is unlikely that muscles undergo such rapid stretches very often, with the possible exception of when a person jumps off a wall or jumps up and down on a pogo stick. However, in these instances, the rapid stretch of the rectus femoris that occurs when the feet or the pogo stick contract the ground causes a reflex contraction that helps prevent the gluteus from being overly bruised. Usually, the postural muscles experience relatively slow, sustained stretches and the anti-gravity muscles, of which the quadriceps is an example, are pulled upon by gravitational forces. This steady force sets up a sustained discharge in each group Ia afferent fiber, but the discharges in different fibers are not synchronized as they are when the tendon is tapped. In addition, longer, larger stretches are able to excite secondary muscle spindle receptors which also have connections with homonymous alpha-motoneurons, di- and trisynaptic ones. These longer, larger stretches therefore activate the alpha-motoneurons by both monosynaptic and polysynaptic reflex pathways. The resulting reflex contraction of the muscle is called the stretch reflex. The polysynaptic effects are not seen in the tendon tap reflex for two reasons: In controlling posture, the asynchronous discharge in mono- and polysynaptic pathways induced by gravitational forces on muscles sums in the alpha-motoneuron with other activity from within the CNS to produce a contraction that just balances the gravitational force. If an additional force is applied, stretching the muscle, additional tension is developed by the stretch reflex to counteract that force. In this way, the stretch reflex serves as a mechanism for maintaining an upright body orientation under a variety of load conditions; the mechanism is automatic "unconscious" and fast msec for the quadriceps in man. In addition to the monosynaptic connections of the group Ia afferent fibers with the homonymous alpha-motoneurons. Thus, the rectus group Ia afferent fibers also excite the vastus alpha-motoneurons, though not as strongly as they do the rectus alpha-motoneurons. Fewer of the synergistic alpha-motoneurons actually discharge, and the subliminal fringe is larger than for homonymous alpha-motoneurons. Most skeletal muscles exhibit a tendon tap reflex, but the reflex is strongest in the antigravity or physiological extensor muscles. This makes some sense in light of the discussion of the last paragraph. Note that physiological extensors are not necessarily anatomical extensors. The biceps brachii are a case in point; they are anatomical flexors of the elbow but they are physiological extensors, moving the forearm against gravity. It is clinically important to note that these reflexes involve only one or two segments of the spinal cord. In fact, the spinal cord can be cut above and below these segments, and the reflexes will still occur. For this reason, testing such reflexes cannot be used as an indicator of the condition of the brain or even other segments of the spinal cord. A circuit diagram showing the collateral of the group Ia afferent fiber synapsing on an inhibitory interneuron that synapses on the alpha-motoneuron of the antagonist muscle. Amsterdam, Elsevier, When the extensor muscle contracts during such a reflex, there is usually a relaxation of its antagonists, the flexor muscles crossing the same joint. If this did not occur, the reflex movement could be

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resisted and diminished by the force of the antagonist muscle 2. The neural mechanism underlying this relaxation of the antagonist muscles is shown in Figure The group Ia afferent fiber, after entering the spinal cord, gives off a collateral branch that synapses on an interneuron. This interneuron, in turn, synapses on the antagonist alpha-motoneuron, in the case of our previous example, a hamstring motoneuron. Its effect on the hamstring alpha-motoneuron is inhibitory, i. This is reciprocal inhibition. Notice that this is a polysynaptic reflex pathway. It is a general principle that anything that has an excitatory or inhibitory influence on an alpha-motoneuron also inhibits or excites the alpha-motoneurons of its antagonist muscle. This is the principle of reciprocal innervation. Thus, for example, excitation of the hamstring alpha-motoneurons by group Ia afferent fibers is accompanied by inhibition of quadriceps alpha-motoneurons. Reciprocal inhibition is a specific example of the more general principle of reciprocal innervation. Therefore according to the principle, if a neuron secretes acetylcholine at one of its terminals, it secretes acetylcholine at all of its terminals. Sir John Eccles has extended this notion to say that the effect of the transmitter released by a single fiber is the same at all its terminals. This would imply that the net result of activity in all group Ia afferent fibers is excitation and only excitation. Thus, if it is necessary to have inhibition in a pathway involving group Ia afferent fibers, then an inhibitory interneuron must be interposed. Some neurons make, or at least contain, more than one of the putative transmitter substances discussed in Chapter However, it is not known whether all of the substances made by a neuron are actually used as transmitter substances by that neuron. Many peptides are thought to be neuromodulators rather than traditional transmitter substances. On the other hand, the idea that the effect of a transmitter substance is everywhere the same is not tenable. It is now known that certain neurons in *Aplysia californica*, the sea slug, secrete acetylcholine at synapses with two different postsynaptic cells, and, in one cell, the transmitter substance evokes an EPSP and, in the other, an IPSP. Thus, the action of the transmitter substance on a neuron depends upon that neuron and the receptors or channels it possesses not on the transmitter substance or the neuron that released it. Whether this behavior is also a characteristic of mammalian neurons is not yet certain. Nevertheless, the usual approach in neurophysiology has been to interpose an interneuron whenever the sign of the effect changes, whether there is direct evidence of an interneuron or not. The flexion reflex Fig. A circuit diagram of the flexion reflex showing afferent fibers from skin, interneurons, and flexor alpha-motoneurons in two spinal cord segments. Note that some interneurons are intersegmental. Amsterdam, Elsevier, If you have ever touched a hot object or stepped on a sharp object and withdrawn your hand or foot, you have experienced a flexion reflex , a nocifensive reflex , or a withdrawal reflex , all terms describing the same event. The protective result of this reflex is obvious; it quickly removes the part of the body from the vicinity of the offending object by contracting the appropriate muscles, usually flexors, and relaxing extensor muscles again, reciprocal innervation. The vigor of the reflex depends upon the strength of the stimulus. A weak pinch produces flexion of the foot; a slightly stronger one, flexion of both the foot and the leg; and a very strong one, flexion of foot, leg, and even hip.

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## Chapter 4 : Muscle Spindles - Comprehensive Physiology Their Messages and Their Fusimotor Supply

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The distribution of muscle receptors in the medial gastrocnemius muscle of the cat. The locations and orientations of spindles are shown in dorsal A and midsagittal B views. The locations of Golgi tendon organs are shown in a midsagittal view only C. The aponeuroses of the muscle are indicated by shaded areas. Swett JE, Eldred E: Now we will deal briefly with three kinds of interoceptors, all found in muscle. These are sometimes termed proprioceptors, because they sense what goes on in the body itself 1. Primary and secondary muscle spindle receptors and Golgi tendon organs all send information about the state of the muscle to the central nervous system. All muscles, with the exception of extraocular and facial musculature, contain all three types of receptors. The spindle receptors sense muscle length and the rate of change of muscle length, whereas the Golgi tendon organ senses muscle tension and the rate of change of muscle tension. We have already seen that receptors in the joints do not signal the angle of the joint. It is likely that muscle spindle receptor messages provide the information the central nervous system uses to compute the angle of joints. In addition, all types of receptors in muscle provide information used in systems that control movement and posture. Muscle spindle afferent fibers The primary and secondary muscle spindle afferent fibers both arise from a specialized structure within the muscle, the muscle spindle, a fusiform structure mm long and m in diameter. The spindles are located deep within the muscle mass, scattered widely through the muscle body, and attached to the tendon, the endomysium or the perimysium, so as to be in parallel with the extrafusal or regular muscle fibers. Although spindles are scattered widely in muscles, they are not found throughout. Figure shows the distribution of spindles in the medial gastrocnemius of the cat, in dorsal A, and midsagittal projections B, and for comparison the location of Golgi tendon organs C. A drawing of a muscle spindle is shown in Figure. The nuclear bag fibers are thicker and longer than the nuclear chain fibers, and they receive their name from the accumulation of their nuclei in the expanded bag-like equatorial region—the nuclear bag. The nuclear chain fibers have no equatorial bulge; rather their nuclei are lined up in the equatorial region—the nuclear chain. This distinction is illustrated in Figure. A typical spindle contains two nuclear bag fibers and nuclear chain fibers. Drawing of a muscle spindle to show the nature of attachment, the arrangement of the intrafusal fibers, and how the afferent and efferent fibers enter the spindle. The sensory innervation of the muscle spindle arises from both group Ia and group II afferent fibers. As shown in Figure, a single, large group Ia fiber coils around the equatorial regions of both nuclear bag and nuclear chain fibers, forming the annulospiral endings or primary muscle spindle receptors. There appears to be only one group Ia afferent fiber per spindle, but every intrafusal muscle fiber within that spindle receives innervation from that fiber. Current thought is that all group Ia afferent fibers form annulospiral endings, and therefore the terms primary muscle spindle afferent fiber and group Ia afferent fiber are used interchangeably. The smaller group II fibers terminate at either end of the nuclear region primarily on the nuclear chain fibers there is apparently some innervation of bag fibers by secondary muscle spindle afferent fibers, but there is disagreement as to how much; they form flower-spray endings or secondary muscle spindle receptors. There usually are several group II fibers innervating each spindle. Not all group II fibers form such endings, so these terms are not synonymous. A nuclear bag and a nuclear chain fiber showing their innervation by group Ia and Group II afferent fibers and gamma motoneurons. Activity in fusimotor neurons produces a contraction of the striated, polar regions of the bag and chain fibers, putting stretch on the equatorial region where the receptor regions are that has few myofibrils and therefore, has little contractility. It is apparently the stretching of this central region, regardless of how it is accomplished, that is the adequate stimulus for both primary and secondary spindle receptors. The fusimotor neurons or gamma-motoneurons should not be confused with the larger

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skeletomotor neurons or alpha-motoneurons, whose activity produces contraction of the extrafusal fibers that do the work of the muscle. The difference in diameter of fusimotor gamma-motoneurons and skeletomotor fibers alpha-motoneurons is illustrated in Figure . The former average about 5  $\mu$ m in diameter, the latter 13  $\mu$ m. Contraction of all the intrafusal fibers at once does not produce any measurable tension in the muscle. The intrafusal fibers are much shorter than the extrafusal fibers, millimeters compared with centimeters. The largest intrafusal fiber, shortening by the same percentage, would only change length by 2%. The extrafusal fiber is therefore capable of a fold greater change in length. The average human striated muscle fiber has a diameter of about 60 micrometers; the intrafusal fiber averages about 10 micrometers. Because the force produced by a skeletal muscle is proportional to its cross-sectional area, the extrafusal fiber is capable of producing at least 36 times more force than the intrafusal fiber. Add these factors to the relative numbers of intrafusal in cat soleus muscle about and extrafusal fibers again in cat soleus muscle about 25, , and it is not hard to see why intrafusal fibers do not generate much force. Fiber spectrum of efferent portion of a muscle nerve. Indicated are A alpha and A gamma fibers, fusimotor and skeletomotor fibers. Composition of Peripheral Nerves. Edinburgh, Livingstone, It also appears that the mechanism for generating force in intrafusal muscle fibers may be different than in extrafusal fibers. There are no action potentials in intrafusal fibers as there are in extrafusal fibers see Chapter 14, with a consequence that one striated end of an intrafusal fiber may contract without the other end doing so. This cannot happen in normal extrafusal fibers. Stretching the equatorial region of the muscle spindle, the adequate stimulus for the receptor, may be accomplished by gamma-motoneuron activation and intrafusal muscle contraction. Another way to stretch the equatorial region of the spindle is to stretch the muscle Fig. Muscle spindle receptors respond to stretch of the muscle and signal muscle length and rate of change of length to the central nervous system. Both primary and secondary spindle afferent fibers give static or length-sensitive responses to stretch, i. Both primary and secondary muscle spindle afferent fibers usually discharge tonically when the muscle is at its resting length. When the muscle is stretched and held at some new length left side of figure, lengthening is an upward deflection of stimulus trace, both types increase their discharge rates and maintain a discharge for as long as the new muscle length is maintained an example of a slowly adapting response. Drawing depicting the stretch of the nuclear region of the spindle caused by stretching the muscle upper pair and by stimulation of gamma motoneurons, causing the striated intrafusal fibers to contract lower pair. Responses of spindle afferent fibers to muscle stretch. A monitor of the stretch lengthening, upward deflection is shown in the upper trace. The response of a primary spindle afferent fiber is shown in the second trace, that of a secondary spindle afferent fiber in the third. This is illustrated in Figure , where the monitor of the muscle length is shown in the top trace and the responses of a primary and secondary spindle afferent fiber are shown in the second and third traces. The greater the muscle length, the greater is the stretch on the spindle and the greater is the static discharge of either type of spindle afferent fiber. In fact, for static conditions, there is an approximately linear relationship between the rate of discharge of the afferent fibers and the length of the muscle. This is illustrated in Figure , which is a plot of discharge frequency versus length of the muscle, for a primary filled circles and a secondary spindle afferent fiber filled squares 2. The frequency of discharge increases monotonically and linearly with increases in muscle length. The slope of these relations is called the position-sensitivity and is usually about the same for primary and secondary spindle receptors. A plot of the frequency of static discharge of a primary and secondary muscle spindle against the length of the muscle. Recordings were made with ventral roots cut. Primary responses are plotted with filled circles. Acta Physiol Scand As the muscle length is being changed, the primary ending signals the rate at which it is being changed. The faster the muscle is stretched, the higher is the rate of discharge of the ending. Figure shows the responses of both primary and secondary spindle endings to two stretches of the muscle at different rates. A monitor of the muscle length is shown in the upper traces, the response of the primary ending is shown in the second traces, and the response of the secondary ending is shown in the third traces of both A and B. Notice that the primary ending responds with a higher frequency during the faster stretch in B, even though the initial and final lengths are the same in each case.

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Also note that the rate of discharge decreases from its peak after the final length has been reached. This decrease defines the dynamic index, which is the difference between the dynamic response frequency for that rate of stretch and the static response frequency for that final length and serves as an indicator of rate sensitivity. When the velocity of stretch is zero, that is, when the muscle length is constant phases 1 and 3 of Fig. The primary spindle codes zero velocity with zero "velocity" discharge, but with an appropriate "length" discharge. When the muscle is changing length, that is, when the velocity is not zero, there will be a velocity response, as well as a length response that is appropriate for the length of the muscle at each given instant of time. Very near the end of phase 2 in Figure, the muscle has nearly reached its final length as in phase 3, but it is still changing length. Because its length is nearly that in phase 3, they can be taken as equal for a first approximation. This gives the following conditions: Figure is a plot of the dynamic index versus velocity or rate of stretch for both primary and secondary endings. The curve for secondary endings is flat compared with that for primary endings, indicating that this receptor has little sensitivity to the velocity of stretch. The monitors of the stretch at two different rates A and B are shown in the upper traces. Note that both stretches start and end at the same muscle length. The responses of a primary ending are shown in the second traces; those of a secondary ending are shown in the third traces. Note the higher frequency of discharge of the primary ending at the higher rate of stretch B. Note that the length of the muscle is changing in phase 2 but is constant in phases 1 and 3 of these records. A plot of the dynamic index versus the rate of stretch for a primary and a secondary muscle spindle afferent fiber. Note the flatness of the secondary curve. *J Physiol Lond* The tap rapidly stretches the spindles upper trace and the primary endings respond to this rapid rate of stretching second trace. The secondary endings, because they lack dynamic sensitivity, respond little if at all to the tap, which produces only a small change in the length of the muscle third trace. After a brief stretch, the spindle returns to its original length, and the discharge of the primary ending stops and then it returns to its prestretch rate of discharge. This behavior will be important in our consideration of the tendon tap reflex 3 Chapter Fusimotor effects on spindle afferent fiber discharges Fusimotor neurons are physiologically separable into two groups based on their effects on the dynamic and static responses of the spindle afferent fibers. Activity in static fusimotor fibers increases the static responses of both primary and secondary spindle afferent fibers, whereas activity in dynamic fusimotor fibers increases the dynamic response in primary spindle receptors. These effects are illustrated in Figure

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## Chapter 5 : Chapter 15 - Reflexes

*Mammalian Muscle Receptors and Their Central Actions (Physiological Social Monograph) [P.B.C. Matthews] on blog.quintoapp.com \*FREE\* shipping on qualifying offers.*

Paine , " Much sensory-motor behavior develops through imitation, as during the learning of handwriting by children. Such complex sequential acts are broken down into distinct motor control synergies, or muscle groups, whose activities overlap in time to generate continuous, curved movements that obey an inverse relation between curvature and speed. How are such complex movements learned through attentive imitation? Novel movements may be made as a series of distinct segments, but a practiced movement can be made smoothly, with a continuous, often bellshaped, velocity profile. How does learning of complex movements transform reactive imitation into predictive, automatic performance? A neural model is developed which suggests how parietal and motor cortical mechanisms, such as difference vector encoding, interact with adaptively-timed, predictive cerebellar learning during movement imitation and predictive performance. To initiate movement, visual attention shifts along the shape to be imitated. This paper contains extensive tabular summaries of the capabilities of these devices. Although these tables are often necessarily incomplete they often contain useful pointers to workers in the field. Table 2 contains summarized information on the force feedback devices reviewed in [33].

Sensory control of locomotion: In the absence of sensory input, the central nervous system can generate a rhythmical pattern of coordinated activation of limb muscles. Contracting muscles have spring-like properties. If synergistic muscles are co-activated in the right way, sustained locomotion can occur. What is the role of sensory input in this scheme? In this chapter we first discuss the implications of positive force feedback control in hindlimb extensor reflexes in the cat. We then raise the question of whether the sensory-evoked responses, which are modest in size and quite delayed in the stance phase, contribute to any significant extent. A locomotor model is used to show that when centrally generated activation levels are low, stretch reflexes can be crucial. However, when these levels are higher, stretch reflexes have a less dramatic role. The more important role for sensory input is probably in mediating higher level control decisions. Another crucial role for sensory input is to allow for higher-level decisions, for example those based on conditional logic in which IF-THEN rules determine state transitions such as phaseswitching.

Low-load prolonged stretch vs. High-load brief stretch HLBS with the results of an experimental method of prolonged knee extension by skin traction, low-load prolonged stretch LLCS. End range of passive knee extension was measured by standard goniometry. Subjects were 11 nonambulatory residents of a nursing home who had demonstrated gradually progressive bilateral knee contractures. Sequential medical trials were used as the clinical research design. Contracture, Knee, Physical therapy. Many elderly individuals demonstrate limited movement.

Dynamic properties of radial and tangential movements as determinants of the haptic horizontal-vertical illusion with an L figure by Tong S. Wong - Journal of Experimental Psychology: In four experiments involving blindfolded subjects, constant errors in the haptic judgment of extent in the horizontal plane were found to relate consistently to the time and velocity of limb movement. Radial movements, executed at a slower speed and for a longer time, are judged longer than tangential movements of equal extent. The data were considered in relation to certain physiological and kinematic properties of the actively moving limb. Taken together with additional information on judgments of movement duration, the results suggest that the illusion of extent is modulated by the perception of differential time cues. In these

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terms, it was noted that the haptic horizontal-vertical illusion with the L figure is another instance of the interaction of apparent space and time commonly found in studies of psychological relativity. Specifically, radial arm movements toward and away from the body, whether along the sagittal or coronal planes, are judged longer than equal tangential movements along the front or side of the body. As radial movements are specific to the horizontal plane, no relative overestimation of haptic extent is found when the L figure is presented in the vertical fronto-parallel Experiments 1, 2, and 3 were completed at the University of Waikato in Hamilton, New Zealand, and supported by New Zealand University Grants Show Context Citation Context Human Movement Science by R. Van Gemmert , " The model suggested how parietal and motor cortical mechanisms, such as difference vector encoding, interact with adaptively-timed, predictive cerebellar learning during movement imitation and predictive performance. Key psychophysical and neural data about learning to make curved movements were simulated, including a decrease in writing time as learning progresses; generation of unimodal, bell-shaped velocity profiles for each movement synergy; size scaling with isochrony, and speed scaling with preservation of the letter shape and the shapes of the velocity profiles; an inverse relation between curvature and tangential velocity; and a Two-Thirds Power Law relation between angular velocity and curvature. However, the Cerebellar ataxia and muscle spindle sensitivity by M. Taylor - J Neurophysiol , " The cerebellum has long been known to participate in movement control. In particular, it has been implicated in the control of the sensitivity of muscle spindle stretch receptors through the fusimotor system. The stretch sensitivity of spindle primary endings can be varied approximately over a 10-fold range by fusimotor efferent action. For many years it has been believed that cerebellar dysfunction is associated with reduced drive to the fusimotor system and that this in turn causes hypotonia by reducing the reflex excitation of extensor motoneurons by spindle afferents. The data on which this hypothesis is based were obtained in anesthetized or decerebrate animals. Little direct information is available on animals or humans performing voluntary movements and exhibiting ataxia or other cerebellar symptoms. We tested the hypothesis by recording from nine muscle spindle afferents in behaving cats before and during reversible inactivation of cerebellar interpositus and dentate nuclei. In normal cats fusimotor action varies with motor task, greatly altering spindle stretch sensitivity. We investigated whether this same range of task-related sensitivity manifested itself during ataxia. We found that the full range of spindle sensitivity was still present during ataxia. We therefore conclude that the cerebellar nuclei studied are not primarily responsible for fusimotor control, nor is the ataxia primarily caused by disordered proprioceptive sensitivity.

### Chapter 6 : CiteSeerX " Citation Query Mammalian Muscle Receptors and Their Central Action

*As muscle spindles are involved in the sensation of position and movement of the body, we tested their involvement in the pathophysiology of idiopathic focal dystonia. Twenty patients with torticollis, nine with writer's cramp, two with blepharospasm and 16 healthy control subjects participated.*