NOTICES OF RECENT PUBLICATIONS


This book can be very strongly recommended to neurologists, neurosurgeons and clinical neurophysiologists, who have the management of patients suffering from neurological disorders of posture, locomotion, respiratory mechanics, eye movements and manual skills. In it Professor Granit has made a systematic survey of the main conceptual and experimental advances of the last twenty-five years, many of them made by himself and his colleagues in Sweden, others directly or indirectly inspired by his teaching. The period dates from his leaving his Nobel-Prize winning work on the retina to take up the physiology of motor control. As he writes, the subject is far from its final synthesis, but keeping up with it is bound to help the clinician in his everyday work, and to encourage the application of the new methods and ideas to the investigation of motor disorders due to central and peripheral lesions in man. For the clinician alone is in a position to fill some of the important gaps in our understanding of voluntary movements. He is likely to find this book a valuable working companion for some years to come, for what is still speculative is amenable in principle to observational and experimental testing. The illustrations of experiments have been carefully chosen and there is an excellent bibliography and index.

The book has two interlinked themes which are treated partly consecutively, partly concurrently: first, the morphology and physiology of the motor apparatus of the spinal segments—γ and α motoneurones, muscle spindles coupled in parallel with motor units, and the nerve centres and pathways that play on the motoneurones; second, the apparatus in action, in so far as it has been possible to observe and measure its performance in men and animals under more or less natural conditions.

The opening chapters review the histochemistry, morphology, metabolism and mechanical responses of the muscle fibres of the slowly and rapidly contracting motor units and of the muscle spindles, highlighting some of the beautiful adaptations which match their performance to the commands they receive from their motoneurones. Next comes the work of Barker, Boyd, Cooper, Laporte and Matthews on the morphology of the primary and secondary endings of the spindles and of the tendon organs, and on their signalling of the length, rate-of-change of length, and tension of passively lengthened muscle. Those muscles whose function is to resist small displacements have large numbers of spindles per unit mass—e.g. the neck muscles in man, so important for steadiness of visual fixation, and enabling people to carry tall water-jars on their heads. Next come the effects on spindle signalling of impulses fired into the intrafusal muscle fibres by the fusimotor (γ) neurones, effects discovered by Leksell in Granit's laboratory in 1944 and developed by Hunt and Kuffler, Laporte, and Matthews. Matthews discovered the existence of two classes of fusimotors—dynamic, which adjust the sensitivity of the primary endings to velocity of lengthening; and static, which adjust the sensitivity of primaries and secondaries to length alone, and can keep these endings signalling even when the muscle is shortening. The static fusimotors are twice to six times as common as the dynamic. There is evidence for some fusimotor innervation by branches of the axons of α motoneurones. The tendon organs respond essentially to active tension (Jansen) and their sensitivity cannot be adjusted by the CNS.
The signals of length and rate-of-change of length are fed by monosynaptic (and also polysynaptic) excitation to the α motoneurones of the muscle of origin and, usually in lesser quantity, to those of its synergists. The same signals inhibit the motoneurones of antagonist muscles by exciting interposed inhibitory interneurones. The fine details of this central distribution, whose study was pioneered by Lundberg, are functionally important in relation to the pattern of locomotion. The signals of the length-measuring secondaries are mediated by interneurones which are subject to control by brain centres. Most experimenters have found that the secondaries excite flexor motoneurones and inhibit extensors, but recent experiments by Matthews have created a very strong presumption that in decerebrate rigidity the secondaries of postural muscles can be interneuronally switched to excite their own motoneurones. The signals from the tension-sensitive tendon organs are responsible for di- or polysynaptic inhibition of motoneurones. The details of their intraspinal distribution are also important for locomotion. The account of the motor apparatus includes a survey of electrophysiological work on the brain stations which send pathways to the static and dynamic γ motoneurones and the tonic and phasic α motoneurones and the interneuronal networks—sensorimotor cortex, cerebellum, red nucleus, vestibular nuclei, etc.: work much of which has "merely served to locate sites of spindle control and, in view of present knowledge, has not been detailed enough to aid in the understanding of how this control is likely to be exercised." It has been important, however, to establish the existence of independent pathways to α and γ motoneurones, which might be important in the execution of specific movements. From the reticular formation, control may serve merely to maintain a background level of spindle activity in readiness for action, as part of a general state of alertness (arousal).

The tracing of all this circuitry has depended on measurements of the quantities of the brief excitatory and inhibitory synaptic actions (post-synaptic potentials) set up in sampled motoneurones by synchronous volleys from primaries, secondaries, tendon organs and central tracts, and of brief changes in the excitability of whole pools, tested by their responses to a monosynaptic input (qualitatively, as by a tendon-jerk; quantitatively, as by the H-reflex); and by sampling the fusimotor output in single γ axons, or by its effect on the activity of primaries and secondaries sampled as dorsal root axons. But all this is of limited interest from the point of view of the essential function of the motoneurones: to discharge trains of impulses over a range of frequencies appropriate to the production of demanded forces and velocities. Granit has pioneered a highly original approach to the physiology of the "firing motoneurone."

The trains of impulses discharged by an α motoneurone to its motor unit arise in a low-threshold firing zone which probably corresponds to the initial segment of the motor axon. There is much to suggest that the excitatory and inhibitory synapses which cover the dendrites, soma and axon hillock may be strategically sited ("adjacent" or "remote") in terms of the changes in membrane potential and membrane conductance that can be detected by an intracellular probe. However this may be, the output of impulses/sec is the language in which the motoneurone encodes the overall balance of excitatory and inhibitory inputs. The "plus" and "minus" inputs are algebraically summed, each adding or subtracting its quota of impulses/sec from the output frequency. A sensitive quantitative measure of the effect of any particular input is the number of impulses/sec added to or subtracted from the frequency generated by the firing zone in response to a steady depolarizing current, injected through an intracellular microelectrode. The effect may be due to excitatory or inhibitory synaptic action on the motoneurone membrane, or to withdrawal of a prevailing excitatory or inhibitory input (disfacilitation or disinhibition).

When first excited, the motoneurone is apt to fire two or more impulses at a high frequency, which favours the prompt development of force by the motor unit. As the discharge proceeds, its frequency falls to a lower level. This fall goes with a change in the after-potential following each impulse; the delayed depolarizations seen after the early impulses give way to more prolonged hyperpolarizations of the cell membrane. This change is interpreted to mean an enlargement of the
firing zone to include the soma and proximal dendrites. Its effect is to stabilize the firing frequency within the range within which exact algebraic summation of synaptic inputs prevails, and to protect the motoneurone from excessive depolarization which would inactivate the impulse-generating membrane. Post-synaptic inhibition (orthodromic, or antidromic from recurrent axon collaterals via Renshaw interneurones) acts similarly.

Granit and his colleagues were among the first to differentiate α motoneurones into two types: "tonic" ("slow," "small") and "phasic" ("fast," "large"). The former, which respond at lowest threshold to the input from the spindles, belong to slowly contracting motor units, and fire over a narrow range of frequency. They have low gain (small slope of linear relation between membrane depolarization and output frequency): excess of excitation over inhibition merely tends to keep them firing very stably at their relatively low ceiling frequency. It may be concluded that an increase in force from slow (postural) muscle would have to depend on recruitment of more motor units. "Phasic" motoneurones have higher gain, and operate over a wider frequency range. There is some evidence that the gain of motoneurones may be adjusted by impulses descending from the brain—a new and exciting idea in motor control.

The properties of the motor apparatus lend naturally to ideas about how postures and movements might be organized in intact animals. The circuit: fusimotor neurones—intramuscular muscles—primary endings—α motoneurones, with the spindles mechanically coupled in parallel to the motor units, led Merton to the follow-up length-servo hypothesis. At some pre-set equilibrium, the circuit would reflexly resist displacement by external forces, the α motoneurones increasing the muscle's output of force in response to stretch of the spindles. To shorten the muscle, the CNS would increase the fusimotor output: the contracting intramuscular muscles would increase the firing of the primary endings, whose increased bombardment of the α motoneurones would shorten the muscle to a new, "demanded" length, that is, the precise length at which the barrage from the primaries would be brought back to the equilibrium level. This idea has been enormously fertile in suggesting experiments. Those revealing fusimotor excitation of spindle primaries by electrical stimulation of brain centres "fitted into this notion but did not necessarily require it." The motor apparatus of the cat's ankle extensors would make it workable there. The spindle primaries are highly sensitive to very small displacements; and electrical stimulation of fusimotor axons can actually fire the α motoneurones across the reflex circuit ("γ loop"). But the absolute quantity of monosynaptic excitation that the ankle-extensors' spindles can generate is large in comparison with the quantity generated by the spindles of some other muscles. Lundberg has stressed the importance of measuring these quantities and also the quantities that the spindles of any muscle may distribute to the α motoneurones of other muscles in the limb.

Another hypothesis is that the CNS excites the α and γ motoneurones together (Granit's "αγ linkage") by some of the structurally independent pathways whose existence has been shown experimentally. Movements could then be "servo-assisted" (Matthews) rather than "servo-driven." The input from the γ-driven primaries would continue throughout the muscle's shortening, reinforcing the excitation of the α's and reciprocally inhibiting their antagonists. If the shortening were checked by a load, the monosynaptic bombardment from the primaries would increase and would increase the output of force. On Granit's view, firing α motoneurones would be specially responsive to changes in the level of the bombardment.

Both these theories neglect the secondary endings and we have, as yet, little idea of how the CNS makes use of their precise length-measuring function.

The follow-up length-servo hypothesis received circumstantial support from experiments on the tonic stretch reflex of the decerebrate cat, whose extensor reflexes are pathologically exaggerated by disconnexion from cerebral control. The tonic stretch reflex is reversibly abolished by selectively paralysing the fusimotor axons with procaine. The increased contraction of the extensors in response to tonic neck reflexes is preceded by increased fusimotor activity. After cutting the dorsal roots, turning the head still increases the fusimotor-driven signalling from the primaries; but the α
motoneurones, which no longer receive these signals, remain silent—the rigidity and the response to head turning is lost. In the anaesthetized cat, fusimotor activity commonly precedes $\alpha$ activity in the flexion reflex. As evidence for the hypothesis, all this is consistent but not compelling. The stretch-reflex experiments were “interpreted on the servo theory though they were originally begun only in order to find out whether the stretch reflex was in need of $\gamma$ bias to occur at all.”

Other systems so far studied all favour the “servo-assistance” theory, but Granit thinks that it would be premature to abandon the follow-up length-servo theory until more cases have been looked at. Respiration has long been valued by physiologists as a spontaneous activity which needs no unphysiological stimuli to evoke it. Experiments on the $\alpha$ and $\gamma$ efferents and spindle afferents of the nerves to inspiratory intercostal muscle were begun independently and simultaneously in Canberra (Sears) and Stockholm (von Euler). It turns out that fusimotor activity does not precede $\alpha$ activity, that “$\alpha\gamma$ linkage” is the rule. If the airway is obstructed, the system can actually function as a load-compensating servo.

Locomotion in the cat is being analysed by workers in Gothenburg and Moscow. The pattern is determined by a “programme” within the CNS, modified by feedback from the muscle receptors. The programme co-activates $\alpha$ and $\gamma$ motoneurones (“$\alpha\gamma$ linkage”) and the primaries continue to signal throughout muscle shortening, so a load-compensating reflex could operate. The central programme starts to activate the extensors before the foot touches the ground, that is, before their spindles can be passively stretched and can reflexly excite the $\alpha$ motoneurones. As the extensors take the weight during the stance phase of the step, they yield, in spite of the load-compensating mechanism. The yielding (?) shock-absorbing) would be favoured by inhibition from the tendon organs, which is distributed appropriately among the extensor $\alpha$ motoneurones of foot, ankle and knee.

A very interesting discussion concludes that no statement can yet be made about the role of muscle afferents in any of the various categories of eye movements. The old belief that eye muscles lack spindles was false, and a wide range of receptor morphology and physiological response has now been collected for different species (Cooper, Daniel, Whitteridge). Static and dynamic fusimotor and primary and secondary endings have yet to be characterized, but there is already some evidence of static $\gamma$ bias. The afferents project to vestibular nuclei, superior colliculi, and centres for neck reflexes, but we know of no monosynaptic connexion to the $\alpha$ oculomotor neurones. Pulling on eye muscles arouses no sensation. Granit provisionally assumes that there must be control circuits which operate “according to the rules discovered in analytically more accessible structures.”

Powerful new techniques, introduced by Hagbarth and colleagues in Uppsala, are now available for studying normal and disordered voluntary movement in man. The signals of single spindle primaries can now be picked up by fine tungsten electrodes inserted percutaneously into human nerves. They reveal “$\alpha\gamma$ linkage” in normal movements. The action of spindle primaries on the CNS can be studied by transverse percutaneous vibration of tendons, which probably excites the primaries selectively; direct longitudinal vibration undoubtedly does so in animals. After a latent period there is a slowly rising excitation of the motoneurones (which contrasts with the abrupt rise in the decerebrate cat). These methods, used in conjunction with procaine or alcohol paralysis of fusimotor axons in the study of movements of prescribed force, velocity and range, are clearly of the greatest promise for clinical research on motor disorders due to lesions of the central nervous system.

There is experimental evidence that intervention with the cerebellum paralyzes the fusimotor system in the decerebrate cat. If spindle paralysis follows cerebellar lesion in man, the resulting loss of the spindle measurements would explain the dysmetria.

So incomplete an outline of the scope of the book can give little idea of the pleasures of reading it. It is a highly personal record of research by a scientist of genius, and, as such, is profoundly
interesting about the elusive nature of the process of scientific discovery. Granit writes modestly that his method is that of "classical physiology," but it would be better described as inspired intuition disciplined always by experimentation. He keeps moving, always starting fresh lines rather than holding up his general advance in order to treat any one line with a degree of sophistication that he would consider unwarranted if biologically implausible over-simplifications had to be made. His choice of openings is helped by a deep and wide background knowledge. All who have worked with him have admired his feeling for his material and have been struck by his instant awareness of the important and unexpected whenever it has turned up during an experiment. When later workers find it profitable to follow his leads with rigorous mathematical formulations and predictions, his clear and steady vision of motor control will help them and their readers in their efforts to see it as a biologically meaningful whole.

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