

DEPARTMENT OF PHYSIOLOGY

ANNUAL REPORT 1962

Staff

Professor

J.C. Eccles, Kt., M.B., B.S., M.A.,
D.Phil., Hon. Sc.D., F.R.A.C.P.,
F.R.S.N.Z., F.A.A., F.R.S.

Professorial Fellow

W.V. Macfarlane, M.A., M.D.

Professorial Fellow in
Neuropharmacology

D.R. Curtis, M.B., B.S., Ph.D.
(from 9.3.62)

Electronics Engineer

J.S. Coombs, M.Sc.

Fellows

J.C. Watkins, M.Sc., Ph.D.

Rosamond M. Eccles, M.Sc., Ph.D.
(from 12th April, 1962)

J.I. Hubbard, B.med.Sci., M.A.,
B.M., B.Ch., Ph.D. (from
12th April, 1962)

Senior Research Fellow

I.R. McDonald, M.D., B.S. (on leave
from mid-April to 16th September,
1962)

Research Fellows

R.J.H. Morris, M.Sc. (resigned
31st May, 1962); R.I. Close, M.Sc.,
Ph.D.; M. Ito, M.D., Ph.D.
(resigned 17th May, 1962);
Y. Løyning, M.D., Ph.D. (commenced
5th June, 1962).

Visiting Fellow of the
National Science Foundation

Professor Talbot H. Waterman, A.B.,
M.A., Ph.D. (commenced 8th October,
1962)

Rockefeller Fellows

P. Andersen, M.D.

T. Yokota, M.D., Ph.D. (commenced
25th October, 1962)

N.I.H. Fellow

W.D. Willis, B.S., B.A., M.D.
(until July)

Wellcome Fellow

T.A. Sears, B.Sc.

Stipendiaat of Netherlands
Organization for the
Advancement of Pure
Research (Z.W.O.)

P. Voorhoeve, M.D. (commenced
6th November, 1962)

Swedish Medical Research
Council Grant & Inter-
national Federation of
University Women

B. Holmqvist, M.D. (commenced
1st November, 1962)

Research Assistants

K.S. Cheah, B.Sc. (commenced
16th April, 1962)

N.E. Stone, M.Sc., Ph.D.
(commenced 30th July, 1962)

/M.M. Campbell

Research Assistants
contd.

M.M. Campbell, B.A. (commenced
2nd October, 1962)

Head Technician

L.M. Davies, Dip. Mech. & Elec. Eng.,
A.M.I.I.T.A., M.Q.E.I.

Students and Teaching Activities

During the year there have been seven students proceeding to the degree of Doctor of Philosophy. Miss Rosemary Kinne, Miss Beth Howard, Dr. W.D. Willis, Dr. R.F. Schmidt, Mr. T. Sears, Dr. T. Oshima and Mr. R.W. Ryall continued their research work for the degree. (Both Dr. Willis and Dr. Schmidt completed their theses before their departure.) Throughout the year there have been departmental seminars, usually every week. Most of the Department attended (in May) the Annual Meeting of the Australian Physiological Society in Melbourne, where thirteen papers were presented by members of the department, and the A.N.Z.A.A.S. Meeting in Sydney in August.

Research Programme

Much of the work reported for 1961 was completed and written up in 1962; some appears in the appended list of published papers, but there are also over 30 papers in press.

Presynaptic inhibition in the spinal cord

The investigations on this recently discovered central inhibitory mechanism (see reports of 1960 and 1961) have been continued with special reference to its organization and to its mechanism. It has been shown that in the spinal cord there are three main systems of presynaptic inhibition, and in general the organization reveals that presynaptic inhibition has the important function of acting as a negative feed-back on the flow of sensory information into the central nervous system and up to higher centres. In particular this negative feed-back is very well demonstrated for the sensory information from cutaneous receptors, which collectively form one of the main systems mentioned above (J.C. Eccles, Schmidt & Willis). The presynaptic inhibitory action from ipsilateral was compared to the effects from contralateral cutaneous afferents. The maximum effect was obtained at 45 msec on the contralateral side compared to 20-25 msec on the ipsilateral. Except for a small group stimulated at 1.0 to 1.2 times threshold, impulses in the larger afferent fibres were always the most effective source of presynaptic inhibition in cutaneous nerves (from either ipsilateral or contralateral hindlimb). Pulses of current through a microelectrode placed in the region of the terminations of the cutaneous afferents caused stimulation of the nearby afferent fibres which was conducted, antidromically, in the lowest afferent fibres to the periphery (Eccles, R.M., Holmqvist & Voorhoeve). The work on presynaptic inhibition in the young kitten was completed and written up for publication (Eccles, R.M. & Willis).

Synaptic mechanisms in the cuneate nucleus

This nucleus is the first relay station for sensory information from the fore-limb to the cerebral cortex. The synaptic mechanisms of this nucleus have been very thoroughly studied by the techniques of field potentials, excitability testing and intracellular recording. In this way it has been shown that impulses ascending the cuneate tract exert a widespread presynaptic inhibition on the transmitting synapses. The inhibitory action of impulses descending from the sensori-motor cortex is also due to presynaptic inhibition. There is also a postsynaptic inhibitory

/control on

control on the transmission, but it is less powerful. The interneuronal pathways responsible for these inhibitory actions have been intensively investigated (Andersen, J.C. Eccles, Schmidt).

Inhibition of transmission through the ventro-basal complex of the thalamus

This part of the thalamus is of great importance because it provides the last link on the main pathway by which general body sensation reaches the cerebral cortex. The physiological processes concerned in thalamic inhibition have been studied by intracellular recording from the thalamic neurones and also by excitability testing both of the presynaptic fibres and of the thalamic neurones. The dominant role of postsynaptic inhibition is revealed by the large and prolonged inhibitory postsynaptic potentials and by the associated depression of direct excitability of thalamic neurones. Presynaptic inhibition also is usually demonstrable by the tests for presynaptic depolarization. The post-synaptic inhibition is largely, if not entirely, a recurrent inhibition because it is very effectively produced by antidromic activation of the thalamo-cortical fibres (Andersen, Brooks, J.C. Eccles & Sears).

Inhibitory potentials in hippocampal pyramidal cells

An investigation of the simplest type of cerebral cortex has been made by intracellular recording from pyramidal cells belonging to the areas CA3 and CA1 of the hippocampus of the cat. To activate the cells three inputs were employed, commissural, septal and local stimulation. Without exception, all three inputs produced large inhibitory post-synaptic potentials (IPSPs) of long duration (200-500 msec). This effect was seen in all cells successfully penetrated. Depth recording of the extracellularly recorded IPSP showed the active site to be located in the cell body layer. The location of the inhibitory synapses at the cell bodies and the wide distribution of the IPSPs from all three inputs suggest that the final link in the inhibitory path is the basket cells described by Cajal and Lorente de No (Andersen, J.C. Eccles & Løynning).

Investigations on the physiology of respiratory movements

The investigation of respiratory motoneurones with intracellular recording was continued, particularly with regard to the effects of repetitive stimulation of low-threshold muscle afferents in the intercostal nerves. The principal finding was that many motoneurones showed a pronounced potentiation of the monosynaptic EPSP with increasing frequency of stimulation up to 2-3 times at 100 c/s. The activity of alpha and fusimotor neurones innervating intercostal muscles was investigated by recording from fine, naturally occurring filaments of the intercostal nerves. It was found that the fusimotor fibres innervating muscle spindles in the external (inspiratory) and internal intercostal muscles (expiratory) are active alternately and that this activity is due to a central control resembling that which governs the alpha respiratory motoneurones. The fibre-calibre spectra of sensory and motor fibres in the intercostal nerves have been constructed from data obtained from chronic experiments on cats in whom dorsal and ventral roots were divided (Sears). The mechanical properties of intercostal muscles were investigated and showed, contrary to recent reports, that 'fast' and 'slow' muscle fibres are present (Andersen & Sears).

Biophysical investigations on nerve cells.

Intracellular electrophoretic injections of several cations into cat spinal motoneurones and spinal ganglion cells have been made in order to investigate their effects upon the motoneuronal potentials, and the processes concerned in their removal. From
/the amount

the amount of depolarization produced by the injections it was suggested that the resting motoneuronal membrane was permeable to cations in the following sequence: $K^+ = Rb^+ Cs^+$ tetramethylammonium (TMA^+) = choline $Na^+ = Li^+ =$ tetraethylammonium (TEA^+). Injection of NH_4^+ caused a fluctuating and often irreversible depolarization, presumably due to a toxic action. The injections of Na^+ , Li^+ and TEA^+ produced the same decrease of the rate of rise of the spike potential. All the cations except K^+ and Rb^+ caused a decrease of the rate of fall of the spike and a reversal of the after-hyperpolarization to a depolarization. The sodium pump was found to extrude Na^+ for motoneurons with a rate constant of about 40 hr^{-1} and Li^+ at about half this rate. TEA^+ , TMA^+ and choline did not appear to be extruded effectively by the pump. Cs^+ was removed from the cells a little faster than Na^+ , but probably diffusional efflux contributed to the removal. The injection of Na^+ into ganglion cells produced changes in resting and spike potentials resembling those with motoneurons. (Ito, Oshima). The importance of the metabolically driven sodium pump in maintaining the intracellular ionic concentration and composition was shown by ventilating cats with 5% O_2 in N_2 or 100% N_2 , which reduced the activity of the pump and produced changes resembling those obtained by Na^+ injection in the resting and spike potentials. There was also often an increase of the monosynaptic EPSP during the hypoxia and anoxia, which had not been observed after the Na^+ injection. It was suggested that the enhanced monosynaptic reflex in the spinal cord during asphyxiation and anoxia might result, not only from the depolarization of the motoneurons, but also from the increased effectiveness of the afferent volley which induced the monosynaptic EPSP (R.M. Eccles, L  yning, Oshima).

Anaesthetics on motoneurons.

Intracellular recording from cat spinal motoneurons has been undertaken to determine the site of action of general anaesthetics in the spinal reflex pathway. A short-acting anaesthetic, thiamylal sodium, produced a decrease in the monosynaptic EPSP, but no change in the critical depolarization for initiating the spike potential. It appears that thiamylal sodium specifically affects the synaptic mechanism (Oshima, Yokota).

Muscle physiology

The mechanical properties of developing rat muscles have been determined in a study of the process of differentiation of muscle into fast and slow types. Other aspects of muscular contraction being examined are the effects of cross-union of nerves to fast and slow muscles, and the force : velocity properties of partially activated striated muscle (R. Close).

Neuropharmacology

Investigations have continued into the pharmacology of centrally located nerve cells in an endeavour to determine the nature of transmitter substances within the mammalian central nervous system. In addition attempts are in progress to extract and isolate such transmitters from brain tissue.

It has been shown, using the electrophoretic technique developed in the department, that neurones in the thalamus and lateral geniculate nucleus are excited by acetylcholine and related substances (Andersen, Curtis). The pharmacology of these neurones differs from that of Renshaw cells which are spinal neurones previously investigated in the department and shown to be excited synaptically by acetylcholine. A structure-activity investigation is in progress, in both the thalamus (Andersen, Curtis) and spinal /cord

cord (Curtis, Watkins, Ryall), in order to correlate the pharmacological behaviour of these types of nerve cell with the known types of cholinceptive receptor. A range of choline esters and closely chemically similar substances have been synthesised for these studies (Watkins, Cheah) and the nicotinic and muscarinic properties determined upon a variety of pharmacological preparations (Ryall). The sensitivity of thalamic and geniculate neurones to acetylcholine probably indicates that this substance functions as a synaptic transmitter but the pathways involved have not been identified. Further studies have been made upon substances related to 5-hydroxytryptamine that depress the synaptic excitation of lateral geniculate neurones by optic nerve volleys (Curtis). It was hoped that this investigation would lead to the identification of the transmitter released from optic nerve volleys but all active compounds hitherto tested merely depress synaptic transmission. The problems of chemical transmission associated with receptors sensitive to either acetylcholine or 5-hydroxytryptamine are of fundamental importance because the alterations in human and animal behaviour produced by compounds such as atropine and lysergic acid diethylamide are presumably associated with the activity of acetylcholine-like or 5-hydroxytryptamine-like compounds as important central transmitters.

Nerve cells throughout the nervous system are excited by acidic amino acids related to glutamic acid and depressed by neutral amino acids related to γ -aminobutyric acid. Many similar compounds have been synthesised in previous years and this programme has continued (Watkins, Cheah). The amino acids have been tested electrophoretically upon spinal, thalamic, geniculate and cortical neurones. The features of amino acid interaction with nerve cell membrane have led to a theoretical and practical investigation of the structure of these membranes (Watkins).

A variety of physico-chemical techniques are being used to separate whole and fractionated brain extracts. Brain homogenates have been separated on sucrose density gradients in the ultracentrifuge and the distribution of pharmacologically active substances has been studied (Ryall). As a preliminary to large scale separation of these and other hitherto unidentified compounds the conditions are being studied for separation and isolation of acetylcholine, 5-hydroxytryptamine and nor-adrenaline (Ryall, Watkins, Stone).

Investigations on presynaptic terminals

During 1962, the study of nerve terminals, initiated in 1961, with the happy cooperation of Drs. Schmidt and Willis, was accelerated by the discovery of a method for recording electrical events in nerve terminals during neuromuscular transmission. This new method, and the previously developed techniques for stimulating and polarizing nerve terminals were used particularly to study the effects of frequency of stimulation. The results were compatible with the hypothesis that the location of the transmitter substance in nerve terminals was altered during normal activity, and in a much more pronounced way by polarizing currents. It seems possible that such changes could be detected with the use of an electron microscope and studies have begun on this aspect of the problem (Hubbard, Schmidt & Willis).

Electronic developments

During the year Differential D.C. Pre-Amplifiers, a Strain-Gauge Control unit, two Integrators with control units and a number of smaller items have been constructed (Coombs).

Water and salt metabolism (Macfarlane, W.V., Morris, R.J.H.
Kinne, R., & Howard, B.)

In the field comparison was made of the content, distribution and turn-over of water in two genetically stabilized lines of sheep at Gilruth Plains. In dry conditions the group with high wool yield consumed more total water than that with a low yield; but on lush vegetation there was no difference between the strains. Further analysis of this genetically determined adaptation will be attempted. At Alice Springs, studies on the water metabolism of desert ruminants were made during a period of hot weather. The tritium turnover of desert cattle was found to be nearly three times greater than that of camels, and that of Merino sheep and red kangaroos, about twice that of camels. Professor K. Schmidt Nielsen kindly provided funds (through the National Science Foundation) and animals for this work. Camels without water appeared to derive 50% of the water needed for sweating from the alimentary tract while sheep depleted the extra-cellular fluids twice as much and as fast as the camel. Camels were found to sweat a solution of potassium bicarbonate, under the stimulus of adrenalin. With support of the Wool Trust Fund studies on African desert animals, to determine water metabolism, were initiated.

In the laboratory the control of water and electrolyte excretion was examined further. The ruminant kidney reacts to vasopressins by excreting potassium. At low rates of flow the excretion of water increases without dependence on urea, sodium or potassium flows. When sheep were changed from high potassium to high sodium status the response of the kidney to vasopressin changed towards that found in man.

Adrenal physiology

A detailed study of the adrenal anatomy of Merino sheep has been completed, and the operative procedure for adrenal autotransplantation has been standardised. Additional experiments to compare the function of the non-transplanted and autotransplanted adrenal glands of conscious sheep have confirmed earlier preliminary findings that autotransplantation does not significantly affect the adrenal corticosteroid secretory function provided the operation has been correctly done (McDonald).

Salivary physiology of sheep

The "stop-flow" method of determining the site of action of hormones on parotid salivary electrolyte exchange has been modified to give better resolution. The site of action of cortisol and aldosterone, which cause reabsorption of Na^+ and secretion of K^+ in the parotid ducts, has been located provisionally in the region of the intralobular "secretory" ducts. It has been demonstrated that the sheep's parotid gland can concentrate iodine up to 50 times the blood plasma concentration, and this occurs in a region more proximal to the gland alveoli than the region of corticosteroid-induced electrolyte transfer. Radioautographic methods are now being used to locate the region of iodine concentration more precisely. Incidental studies of parotid salivary duct pressures, to validate the above work, suggests that contraction of the salivary ducts is an initial event when the secretomotor (parasympathetic) nerve is stimulated, and the possibility that myoepithelial cells may play a role in maintaining the flow of saliva at rapid rates is now being examined (McDonald).

/Other activities

Other activities

Sir John Eccles was awarded the Cook Medal by the Royal Society of New South Wales and a Royal Medal by the Royal Society of London. He was overseas from August 28 to October 25, and attended three International Meetings and four symposia at which he contributed 8 papers, seven of which are being published. He lectured at Oxford, Birmingham, Chicago, Ann Arbor, Philadelphia, Boston, Harvard and San Francisco; at the A.N.Z.A.A.S. Meeting in Sydney, and in Canberra to the Australian Society of Anaesthetists and the Society of Neurosurgeons. He gave a guest of Honour Broadcast on the A.B.C. Dr. Curtis attended the First Asian and Oceanian Congress of Neurology held in Tokyo. He gave lectures and seminars at the University of Tokyo; Istituto Superiore di Sanita, Rome; Institute of Animal Physiology, Babraham; the Medical School, Birmingham and the Department of Pharmacology, Oxford. Dr. Hubbard was given a Royal Society Grant to permit him to spend six months in the Department of Biophysics, University College, London, from September. Dr. Hubbard and Dr. Willis attended three International Conferences in Europe in September at which they presented three papers.

Dr. W.V. Macfarlane contributed a review and three papers at the UNESCO Symposium on Physiology in Arid Regions held in Lucknow in December, 1962.

Dr. McDonald took leave without pay to spend five months at the A.R.C. Institute of Animal Physiology, Babraham, near Cambridge, England, on the invitation of the Director, with the assistance of a Wellcome Travel Grant and an A.R.C. Research Fellowship.

Overseas visitors to the department during the year included:

Professor S.W. Kuffler from 22nd to 29th January;

Professor C.McC. Brooks from 20th February to 20th May;
He gave lectures and seminars and participated in research;

Professor C.M. Pomerat from 12th to 20th March;
He gave several lectures and seminars.

During the year the Wellcome Trust provided an Aminco Bowman spectrophotofluorometer as a gift to the department. This has proved of invaluable assistance in the brain extract programme.

/PUBLICATIONS

PUBLICATIONS

Andersen, P. & Eccles, J.C.

'Inhibitory phasing of neuronal discharge.' Nature, Lond. 196, 645-647.

Andersen, P., Eccles, J.C. & Schmidt, R.F.

'Presynaptic inhibition in the cuneate nucleus.' Nature, Lond. 194, 741-742.

Andersen, P., Eccles, J.C. & Sears, T.A.

'Presynaptic inhibitory action of cerebral cortex on the spinal cord.' Nature, Lond. 194, 740-741.

Araki, T., Ito, M., Kostyuk, P.G., Oscarsson, O. & Oshima, T.

'Injection of alkaline cations into cat spinal motoneurones.' Nature, 196, 1319-1320.

Close, R.

'The pattern of activation of the sartorius muscle of the frog.' J. Gen. Physiol. 46, 1.

Curtis, D.R.

'Direct extracellular application of drugs.' Biochem. Pharmacol. 9, 205-212.

Curtis, D.R.

'Action of 3-hydroxytyramine and some tryptamine derivatives on spinal neurones.' Nature, Lond. 194, 292.

Curtis, D.R. & Andersen, P.

'Acetylcholine: a central transmitter.' Nature, Lond. 195, 1105-1106.

Curtis, D.R. & Davis, R.

'Pharmacological Studies upon Neurones of the Lateral of the cat.' Brit. J. Pharmacol. 18, 217-246.

Eccles, J.C.

'The central connexions of muscle-receptors.' In "Muscle-Receptors." Ed. D. Barker, Golden Jubilee Publication. University of Hong-Kong. pp. 81-101.

'Bases Neurophysiologiques de l'Esprit.' Chapter IV, of La Vie et l'Homme. Edited by Herman Gregoire. Geneve: Rene Kister.

'Abnormal connections in the central nervous system.' In Progress in Neurobiology: V. Neural Physiopathology - R.G. Grenell, pp. 16-38. New York, Harper & Row.

Eccles, J.C., Eccles, R.M. & Kozak, W.

'Further investigations on the influence of motoneurones on the speed of muscle contraction.' J. Physiol. 163, 324-339.

Eccles, J.C., Eccles, R.M. & Shealy, C.N.

'An investigation into the effect of degenerating primary afferent fibers on the monosynaptic innervation of motoneurons.' J. Neurophysiol. 25, 544-58

Eccles, J.C., Eccles, R.M., Shealy, C.N. & Willis, W.D.

'Experiments utilizing monosynaptic excitatory action on motoneurons for testing hypotheses relating to specificity of neuronal connections.' J. Neurophysiol. 25, 559-580.

Eccles, J.C., Kostyuk, P.G. & Schmidt, R.F.

'Central pathways responsible for depolarization of primary afferent fibres.' J. Physiol. 161, 237-257.

'Presynaptic inhibition of the central actions of flexor reflex afferents.' J. Physiol. 161, 258-281.

Eccles, J.C., Kostyuk, P.G. & Schmidt, R.F.

'On the nature and functional significance of the electrotonic potential of the dorsal root of the spinal cord.' J. Physiol. Kiev. 8, 21-37.

'The effect of electric polarization of the spinal cord on central afferent fibres and on their excitatory synaptic action.' J. Physiol. 162, 138-150.

Eccles, J.C., Magni, F. & Willis, W.D.

'Depolarization of central terminals of group I afferent fibres from muscle.' J. Physiol. 160, 62-93.

Eccles, J.C., Schmidt, R.F. & Willis, W.D.

'Presynaptic inhibition of the spinal monosynaptic pathway.' J. Physiol. 161, 282-297.

Eccles, J.C., Willis, W.D. & Schmidt, R.F.

'Primary afferent depolarization of Group Ib afferent fibres of muscle.' Communication no. 919. XXII Intern. Cong. Physiol. Sci. Leiden.

Eccles, R.M. & Iggo, A.

'The double twitch of the gracilis muscle.' J. Physiol. 159, 500-506.

Eccles, R.M., Kozak, W. & Westerman, R.A.

'Enhancement of spinal monosynaptic reflex responses after denervation of synergic hind-limb muscles.' Exp. Neurol. 6, 451-464.

Eccles, R.M., Sears, T.A. & Shealy, C.N.

'Intracellular recording from respiratory motoneurons of the thoracic spinal cord of the cat.' Nature, Lond. 193, 844.

Hubbard, J.I. & Oscarsson, O.

'Localization of the cell bodies of the ventral spino-cerebellar tract in lumbar segments of the cat.' J. comp. Neurol. 118, 199-204.

Hubbard, J.I. & Schmidt, R.F.

'Repetitive activation of motor nerve endings.' Nature, 196, 378-379.

Hubbard, J.I. & Willis, W.D.

'Hyperpolarization of mammalian motor nerve terminals.' J. Physiol. 163, 115-137.

'A method for investigation of the transmitter release mechanism.' Communication No. 852. XXII Inter. Cong. of Physiol. Sci. Leiden, 1962.

'Mobilisation of transmitter by hyperpolarization.' Nature, Lond. 193, 174-175.

'Reduction of transmitter output by depolarization.' Nature, 193, 1294-1295.

Ito, M., Kostyuk, P.G. & Oshima, T.

'Further study on anion permeability of inhibitory post-synaptic membrane of cat motoneurones.' J. Physiol. 164, 150-156.

Ito, M. & Oshima, T.

'Temporal summation of the after-hyperpolarization following a motoneurone spike.' Nature, Lond. 195, 910-911.

Kozak, W., Macfarlane, W.V. & Westerman, R.

'Long-lasting reversible changes in the reflex responses of chronic spinal cats to touch, heat and cold.' Nature, Lond. 193, 171-173.

Magni, F. & Oscarsson, O.

'Comparison of ascending spinal tracts activated by Group I muscle afferents in the phalanger, rabbit and cat.' Acta physiol. Scand. 54: 37.

Macfarlane, W.V.

'Antidiuretic hormone assay and clinical implications.' Clinical Endocrinology. 1, 637-648.

'Adaptation of Merinos to the arid tropics.' In "The Simple Fleece." Ed. Alan Barnard, A.N.U. and M.U.P. 106-121.

Morris, R.J.H., Howard, B. & Macfarlane, W.V.

'Interaction of nutrition and air temperature with water metabolism of merino wethers shorn in winter.' Aus. J. Agr. Res. 13, 320-334.

Ryall, R.W.

'The subcellular distribution of substance P and 5-HT in brain.' Biochem. Pharmacol. 11, 1234.

'Subcellular distribution of pharmacologically active substances in guinea pig brain.' Nature, 196, 680-681.

Watkins, J.C.

'The synthesis of some acidic amino acids possessing neuropharmacological activity.' J. Med. Pharm. Chem. 5, 1187-1199.

ACCEPTED FOR PUBLICATION

Andersen, P., Brooks, C.McD. & Eccles, J.C.

'Electrical responses of the ventrobasal nucleus of the thalamus.' Third Int. Meeting Neurobiologists, Kiel.

Boyd, I.A. & Eccles, J.C.

'Fast- and also-conducting small motor fibres in nerves to mammalian skeletal muscle.' J. Physiol.

Curtis, D.R.

'The microelectrophoretic extracellular application of pharmacologically active substances.' In 'Physical Techniques in Biological Research.' Ed. by W.L. Nastuk. Vol. 5, New York, Academic Press.

'Acetylcholine as a central transmitter.' Canad. J. Biochem. Physiol.

'The effect of some psychotomimetic drugs upon single nerve cells.' Proceedings Sec. Int. Conference of Manfred Sakel Foundation.

'The depression of spinal inhibition by electrophoretically administered strychnine.' Int. J. Neuropharmacol.

'The pharmacology of central and peripheral inhibition.' Pharmacol. Rev.

Curtis, D.R. & Davis, R.

'The excitation of lateral geniculate neurones by quaternary ammonium derivatives.' J. Physiol.

Curtis, D.R. & Watkins, J.C.

'Acidic amino acids with strong excitatory actions on mammalian neurones.' J. Physiol.

Eccles, J.C.

'Homeostatic mechanisms in the nervous system.' In "Perspectives in Biology." Elsevier Pub. Co.

'Spinal neurones: Synaptic connexions of neurones in relation to chemical transmitters and pharmacological responses.' J. Biochem. Pharmacol.

'Postsynaptic and presynaptic inhibitory actions in the spinal cord.' In 'Specific and Unspecific Mechanisms of Sensory-Motor Integration.' Pub. by 'Inter. Brain Res. Organization', Paris.

'Interrelationship between nerve and muscle cell.' In symposium on the effect of use and disuse on neuromuscular functions. Czechoslovak Academy of Sciences.

'Specificity of neural influence on speed of muscle contractions.' In symposium on effect of use and disuse on neuromuscular functions. Czechoslovak Academy of Sciences.

Eccles, J.C. (contd.)

'Specificity of monosynaptic innervation of motoneurones.'
In symposium on the effect of use and disuse on neuromuscular functions. Czechoslovak Academy of Sciences.

'Mind, the ultimate expression of the living state.'
Symposium "The Living State." Pub. by Western Reserve University, Cleveland.

Eccles, J.C., Eccles, R.M., Ito, M.

'Effects on intracellular potassium and sodium injections on the inhibitory postsynaptic potential.' J. gen. Physiol.

'Effects produced on inhibitory postsynaptic potentials by the coupled injections of cations and anions into motoneurones.'
J. Gen. Physiol.

Eccles, J.C., Schmidt, R.F. & Willis, W.D.

'Pharmacological studies on presynaptic inhibition.'
J. Physiol.

'Depolarization of central terminals of Group Ib afferent fibers of muscle.' J. Neurophysiol.

'The location and the mode of action of the presynaptic inhibitory pathways on to Group I afferent fibers from muscle.'
J. Neurophysiol.

'The mode of operation of the synaptic mechanism producing presynaptic inhibition.' J. Neurophysiol.

'Inhibition of discharges into the dorsal and ventral spinocerebellar tracts.' J. Neurophysiol.

'Depolarization of the central terminals of cutaneous afferent fibres.' J. Neurophysiol.

Eccles, R.M.

'Patterns of Renshaw cell distribution.' Actualites Neurophysiologiques, Vol. 4. Paris: Masson & Cie.

'Orthodromic activation of single ganglion cells.' J. Physiol.

Eccles, R.M., Shealy, C.N. & Willis, W.D.

'Patterns of innervation of kitten motoneurones.' J. Physiol.

Eccles, R.M., Willis, W.D.

'Presynaptic inhibition of the monosynaptic reflex pathway in kittens.' J. Physiol.

Hubbard, J.I. & Schmidt, R.F.

'An electrophysiological investigation of mammalian motor nerve terminals.' J. Physiol.

Hubbard, J.I. & Willis, W.D.

'The effect of use on the transmitter release mechanism at the mammalian neuromuscular junction.' In symposium on the effect of use and disuse on neuromuscular functions. Czechoslovak Academy of Sciences.

Ito, M. & Oshima, T.

'The extrusion of sodium from the spinal motoneurons of the cat.' J. gen. Physiol.

Macfarlane, W.V.

'Endocrine responses to hot environments.' In "Physiological responses to hot dry environments" ed. UNESCO, in press.

'The pain producing properties of the stinging tree, Laportea." In "Venomous and poisonous animals and noxious plants of the Pacific Region." Edited by H.L. Keegan and W.V. Macfarlane. Pergamon Press, Oxford.

Macfarlane, W.F., Morris, R.J.H. & Howard, B.

'Turnover and distribution of water in desert camels, sheep, cattle and kangaroos.' Nature (in press)

Schmidt, R.F. & Willis, W.D.

'Intracellular recording from motoneurons of the cervical spinal cord of the cat.' J. Neurophysiol.

'Depolarization of central terminals of afferent fibers in the cervical spinal cord of the cat.' J. Neurophysiol.