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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The main point of the project is to study the relation between the parameters of movement and the motor output patterns to the working muscles in order to obtain information about the underlying control system. Several lines of investigation have been used in addition to input-output studies with human subjects. The input, largely comprising information from muscle receptors, has been further illustrated by specific studies of muscle spindle receptors and nerve membrane properties. The central organization has been studied in various animal experiments in various motor control problems including the neural control of

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respiration and vestibular organization. In addition, computer simulations of small neuronal networks have added an understanding of circuits involved in motor performance.

DYNAMIC CHARACTERISTICS OF HUMAN MOTOR PERFORMANCE IN CONTROL SYSTEMS

AFOSR-TR- 80-0760 AFOSR-75-2804

FINAL REPORT
(Sept. 1975- Nov 1979)

In the period covered by this report, September, 1975 through November, 1979, the computer facilities made available to the Laboratory of Neurophysiology by the above referenced grant have been an essential part of the research and teaching activities of the staff and pre- and post-doctoral Fellows. The research projects conducted during this period were on the following principal topics:

1. Motor control and perceptual-motor organization
2. Receptor properties
3. Membrane properties of neurons
4. Organization of the central control of respiration
5. Data processing by small neuronal networks.

The results of these investigations have been published or are in the process of being published; a complete list is provided in Appendix I. A brief summary description of the principal results in each of the research areas follows.

1. Motor control and perceptual-motor organization.

The research projects in this area include studies of reflex control of movement and position in the human and in trained animals. The studies involve determinations of the relationship between isometric tension and EMG activity in man as well as the visco-elastic properties of human muscle; the relationship between vestibular inputs and muscle activity in awake cats; the unit activity in cerebellar nuclei and red nucleus during ongoing movements in trained animals; a mathematical description of the reflex mechanisms leading to correction for load disturbances and during tracking movements; the logic whereby motor patterns are represented in the nervous system. Findings include a detailing of linear and non-linear features of motor activity in biceps and triceps muscles of man as well as time variations in reflex gain and reflex dynamics during intentionally controlled movements, and the identification of a general principle, valid for both learned and spontaneously initiated movements, that relates the trajectory to the speed of motion through a constant.

2. Receptor Properties.

The research in this area has dealt with the biophysical properties underlying the behavior of mechanoreceptors and has focused on the behavior of the mammalian muscle spindle to provide more precise descriptions of its behavior in the motor control problem. Contributions made by the passive mechanical properties of intrafusal muscle as well as the role of fusimotor activation in determination of the spindle response to stretch have been determined. The non-linear dependence of muscle spindle response on the velocity and amplitude of muscle stretch and the way in which this behavior is influenced by motor commands were described and analyzed.

3. Membrane Properties of Neurons.

This research has focused on two areas that are involved in the encoding of information by nerve cells. One was directed to an increased understanding of the mechanisms and properties of repetitive firing in sensory neurons, and the other to an analysis of specific membrane mechanisms responsible for potassium conductance. Tonic repetitive firing has been modeled for the first time for a normal, non-space-clamped membrane. Non-uniformities of membrane excitation properties were taken into account and results show a marked lowering of and linearization of the impulse frequency with stimulus intensity. The role of the electrogenic pumping of ions across the membrane in the encoding process was delineated in detail and the excitation parameters of the impulse trigger zone were derived from a statistical evaluation of impulse trains using a systems analysis approach.

Voltage clamp studies in squid axon and extensive computer modeling are helping to illuminate the role of diffusion and potential energy profiles in the nerve membrane in the determination of electrical conductance across the membrane.

4. Organization of the Central Control of Respiration.

The role of the medullary-pontine interactions in the control of respiration has been studied using anatomical tracing, designed to locate the pathways and nuclei involved, and electrophysiological techniques designed to determine patterns of neuronal discharge of the various elements in the pathways. Together these studies have revealed a previously

unreported substructure of the medulla wherein neurons are organized in thin sheets which run longitudinally within the brainstem.

Microelectrode recordings were made from neurons in the brainstem of the cat in regions thought to be involved in generating the respiratory rhythm. Results are consistent with the hypothesis that respiration is controlled at the bulbopontine level by the time course of activity in a pool of central inspiratory inhibitory neurons whose activity is greatest early in expiration, then gradually decays during expiration to a level at which inspiratory neurons are released.

5. Data Processing by Small Neural Networks.

These studies included both the development of a program for the IBM 1800 for the stimulation of small neuronal networks and experimental studies that were analyzed by means of the simulations. System identification techniques that rely on noise signals as input were used to determine input-output relationships in the neurons of Clarke's column of the spinal cord. Results show that extracellular recording of impulse activity could be used to deduce excitatory and inhibitory interactions intracellularly and it revealed an extensive convergence of sensory input as well as descending influences from the brain stem reticular formation. Patterns of neuronal discharge from brain-stem neurons thought to be involved in generating respiratory rhythms were correlated with different phases of the respiratory cycle. Spike activities of two simultaneously recorded neurons were cross-correlated to detect possible synaptic interactions. Simulations of known neural interactions were used to interpret resulting patterns.

APPENDIX I. Publications from the Laboratory of Neurophysiology 1975-1980

1975 1. Fohlmeister, Jurgen F. Adaptation and accomodation in the squid axon. Biol. Cybernetics 18:49-60.

2. Soechting, J.F. and W.J. Roberts. Transfer characterisitics between EMG activity and muscle tension under isometric condtions in man. J. Physiol. (Paris) 70:799.

3. Knox, Charles K. and Richard E. Poppele. Response of neuronal systems to random pulse trains: Theory and experimental results from Clarke's column neurons. Proc. 1st Symposium on Testing and Identification of Nonlinear Systems (G.D. McCann and P.Z. Marmarelis, eds.), Cal. Tech. Inst. Tech. Press, pp. 227-235.

4. Fohlmeister, J.F., R.E. Poppele and R.L. Purple. Determination of neuronal feedback parameters from spike train analysis. Neurosci. Abst. 1:680.

5. Poppele, Richard E. and W.R. Kennedy. Dependence of muscle spindle sensitivity on muscle length. Neurology 25:393-4.

6. Dawis, S. and R.E. Poppele. Evidence for multiple encoder sites in primary endings of mammalian muscle spindles. Neurosci. Abst. 1:182.

7. Anderson, J.H., J.F. Soechting and C.A. Terzuolo. Vestibular influences on triceps brachii in decerebrate and decerebellate cats. Neurosci. Abst. 1:250.

8. Knox, C.K. and G.W. King. Changes in the Breuer-Hering reflexes following lesions in the parabrachial nucleus of the cat. Society for Neuroscience.

1976 9. Ranish, N.A. and J.F. Soechting. Studies on the control of some simple motor tasks. Effects of thalamic and red nuclei lesions. Brain Research 102:339.

10. Soechting, J.F., N.A. Ranish, R. Palminteri and C.A. Terzuolo. Changes in a motor pattern following cerebellar and olivary lesions in the squirrel monkey. Brain Research 10^5:21.

11. Viviani, P., J.F. Soechting and C.A. Terzuolo. Influence of mechanical properties on the relation between EMG activity and torque. J. Physiol. (Paris) 72:45.

12. Gur, Moshe and Richard L. Purple. Blood pressure responses as an indicator of the anesthetic level in ground squirrels. J. Appl. Physiol. 40: No. 6, 977-981.

13. Beitz, Alvin J. and Gary W. King. An improved technique for the micro-injection of horseradish peroxidase. Brain Research 108:175-179.

14. Lestienne, F., J.F. Soechting and A. Berthoz. Postural reorganizations induced by linear movement of a visual scene. Third Int'l. Symposium on Motor Control. Abst. 44.

15. Soechting, J.F., C.A. Terzuolo and P. Viviani. Cerebellar control of segmental reflex mechanisms in the context of initiation and control of movement. Third Int'l. Symposium on Motor Control. Abst. 67.

16. Knox, C.K. and G.W. King. Changes in the Breuer-Hering reflexes following rostral pontine lesion. Resp. Physiol. 28:189-206.

1977 17. Anderson, John H., J.F. Soechting and C.A. Terzuolo. Dynamic relations between natural vestibular inputs and activity of forelimb extensor muscles in the decerebrate cat. I. Motor output during sinusoidal linear accelerations. Brain Research 120:1-15.

18. Anderson, John H., J.F. Soechting and C.A. Terzuolo. Dynamic relations between natural vestibular inputs and activity of forelimb extensor muscles in the decerebrate cat. II. Motor input during rotations in the horizontal plane. Brain Research 120:17-23.

19. Soechting, J.F., J.H. Anderson and Alain Berthoz. Dynamic relations between natural vestibular inputs and activity of forelimb extensor muscles in the decerebrate cat. III. Motor output during rotations in the vertical plane. Brain Research 120:35-47.

20. Anderson, John H., Alain Berthoz, J.F. Soechting and C.A. Terzuolo. Motor output to deafferented forelimb extensors in the decerebrate cat during natural vestibular stimulation. Brain Research 122:150-153.

21. Fohlmeister, J.F., R.E. Poppele and R.L. Purple. Repetitive firing: A quantitative study of feedback in model encoders. J. Gen. Physiol. 69: 815-848.

22. Fohlmeister, J.F., R.E. Poppele and R.L. Purple. Repetitive firing: A quantitative analysis of encoder behavior of the slowly adapting stretch receptor of crayfish and eccentric cell of Limulus. J. Gen. Physiol. 69: 849-877.

23. King, G.W. and C.K. Knox. Bulbo-pontive pathways possibly subserving respiration as studied with neuroanatomical tracing technqiues. XXVII Int'l. Congress Physiol. Sciences 13:385.

24. Knox, C.K. and R.E. Poppele. Correlation analysis of stimulus evoked changes in excitability of spontaneously firing neurons. J. Neurophysiol. 40:616-625.

25. Knox, C.K., S. Kubota and R.E. Poppele. A determination of excitability changes in DSCT neurons from spike train analysis. J. Neurophysiol. 40: 626-646.

26. Kubota, S. and R.E. Poppele. Evidence for control of DSCT activity by the brain stem reticular formation. Brain Research 129:361-365.

27. Viviani, P. and C.A. Terzuolo. Engrammes moteurs dans le traitement de l'information linguistique. Conference on Motor Control, Marseille, volume in press.

1978 28. Dufresne, J.R., V.S. Gurfinkel, J.F. Soechting and C.A. Terzuolo. Response to transient disturbances during intentional forearm flexion in man. Brain Research 150:103-115.

29. Sanchez-Robles, S. and J.H. Anderson. Compensation of vestibular deficits in the cat. Brain Research 147:183-187.

30. Soechting, J.F., J.E. Burton and N. Onoda. Relationships between sensory input, motor output and unit activity in interpositus and red nuclei during intentional movement. Brain Research 152:65-79.

31. Terzuolo, C.A., J.F. Soechting and J.R. Dufresne. Adaptive properties of the myotatic feedback. Proceedings of the International Brain Research Organization, Pisa, Italy.

32. Dufresne, J.R., J.F. Soechting and C.A. Terzuolo. EMG response to pseudo-random torque disturbances of human forearm position. Neuroscience 3:1213-1226.

33. Terzuolo, C.A. and P. Viviani. About the central representation of learned motor patterns. Proceedings, Symposium on Posture and Movement: Perspectives for Integrating Neurophysiological Research on Sensorimotor Systems (in press).

34. Chen, W.J. and R.E. Poppele. Small signal analysis of the response of mammalian muscle spindles with fusimotor stimulation and a comparison with large signal responses. J. Neurophysiol. 41:15-27.

35. Soechting, J.F. and S.S. Robles. Dynamic properties of cat tenuissimus muscle. Soc. Neurosci. Abst. 4.

36. Dufresne, J.R. and J.F. Soechting. Reflex modulation during ongoing motor tasks. Soc. Neurosci. Abst. 4.

37. Robles, Sofia Sanchez. Dynamics of cat tenuissimus muscle. M.S. Thesis, University of Minnesota.

38. Ashby, P., D. Zilm and R.E. Poppele. The IA EPSP in man. Soc. Neurosci. Abst. 4:563.

39. Fohlmeister, J. A non-ohmic current-conductance correlation exhibited by the K-channel of the squid giant axon. Symposium on Membrane Structure and Function, Wairakai, New Zealand, 1978.

40. Knox, C.K. Reflex and central mechanisms controlling expiratory duration. Wenner-Gren Center Symposium on Central Nervous Control Mechanisms in Regular, Periodic and Irregular Breathing, Stockholm, 1978.

41. King, G.W. A neuroanatomical and neurophysiological investigation of the bulbo-pontine circuits contributing to the rhythmicity of respiration in the cat. Ph.D. Thesis, University of Minnesota.

42. Holloway, S.F. and R.E. Poppele. Evidence for electrogenic pumping in cat muscle spindle. Brain Research 154:144-147.

43. Poppele, R.E., W.R. Kennedy and D.C. Quick. Mechanical properties of the intrafusal muscle of mammalian muscle spindles. Soc. Neurosci. Abst. 4: 518.

44. Gur, Moshe and R.L. Purple. Retinal ganglion cell activity in the ground squirrel under halothane anesthesia. Vision Research 18:1-14.

45. Anderson, J.H. and C. Pappas. Neck motor responses to vertical rotations in the alert cat. Soc. Neurosci. Abst. 4:1936.

46. Prech, T.W. and J.H. Anderson. Otolith-ocular and canal-ocular reflexes: their relative contribution to the vestibulo-ocular reflex. 11 European Neuroscience Meeting. Neuroscience Letters, Suppl. 1.

47. Robles, Sofia Sanchez and J.H. Anderson. Compensation of vestibular deficits in the cat. Brain Research 147:183-187.

48. Anderson, J.H., R.H.I. Blanks and W. Precht. Response characteristics of semicircular canal and otolith systems in the cat. I. Dynamic responses of primary vestibular fibers. Exp. Brain Res. 32:491-507.

49. Blanks, R.H.I., J.H. Anderson and W. Precht. Response characteristics of semicircular canal and otolith systems in the cat. II. Responses of trochlear motoneurons. Exp. Brain Res. 32:509-528.

50. Fohlmeister, J.F. A mechanism for the production of very low frequency repetitive firing from nerve encoders under constant current stimulation. Neurosci. Abst. 4:388.

51. King, G.W. Topography and electrophysiology of connections between cells of the medulla and nucleus parabrachialis. Wenner-Gren Center Symposium on Central Nervous Control Mechanisms in Regular, Periodic and Irregular Breathing, Stockholm.

52. King. G.W. Topography of ascending brainstem projections to nucleus parabrachialis in the cat. (Submitted for publication.)

53. Knox, C.K. Reflex and central mechanisms controlling expiratory duration. Symposium on Central Nervous Control Mechanisms in Regular, Periodic and Irregular Breathing, Wenner-Gren Center, Stockholm. In press.

54. Dawis, S.M. A model for light adaptation: Producing Weber's Law with bleaching-type kinetics. BioCybernetics 30:187-193.

1979 55. Anderson, J.H. and C. Pappas. Role of central pathways mediating vestibulo-neck reflexes in the alert cat. 111 European Neuroscience Meeting.

56. Anderson, J.H. and W. Precht. Otolith responses of extra-ocular muscles during sinusoidal roll rotations. Brain Research 160:150-154.

57. Knox, C.K. Phase shifting of the respiratory cycle produced by electrical stimulation of the medial pontine reticular formation. Soc. Neurosci. 5: 44.

58. Fohlmeister, J.F., W.J. Adelman, Jr. and R.E. Poppele. Membrane excitation properties from a statistical evaluation of impulse trains. Neurosci. Abst. 5:292.

59. Poppele, R.E., D.C. Quick and W.R. Kennedy. Contribution of intrafusal viscoelasticity to muscle spindle adaptation. Neurosci. Abst. 5:383.

60. Poppele, R.E., D.C. Quick and W.R. Kennedy. A determination of static mechanical properties of intrafusal muscle in isolated cat muscle spindles. Neurosci. 4:401-411.

61. Gur, M. and R.L. Purple. Some temporal output properties of color opponent units in the ground squirrel retina. Brain Research 16:233-244.

62. Soechting, J.F. and A. Berthoz. Dynamic role of vision in the control of posture in man. Exp. Brain Res. 36:551-561.

63. Anderson, J.H., J.F. Soechting and C.A. Terzuolo. Role of vestibular inputs in the organization of motor output to forelimb extensors. Symposium on Reflex Control of Posture and Movements. Prog. in Brain Res. In press.

64. Precht, W., J.H. Anderson and R.H.I. Blanks. Canal-otolith convergence on cat ocular motoneurons. Symposium on Reflex Control of Posture and Movements. Prog. in Brain Res. In press.

65. Precht, W. and J.H. Anderson. Effects of cerebellectomy on the cat's vertical vestibulo-ocular reflex. Pflügers Arch. In press.

66. Dawis, S.M. Light adaptation in cone receptors: the occurrence and significance of unitary adaptive strength. Biol. Cybernetics 34:35-41.

67. Fohlmeister, J.F. Excitation parameters of the repetitive firing mechanism from a statistical evaluation of nerve impulse trains. Biol. Cybernetics 34:227-232.

68. Anderson, J.H., W. Precht and C. Pappas. Changes in the vertical vestibulo-ocular reflex due to kainic acid lesions of the interstitial nucleus of Cajal. Neurosci. Letters. In press.

69. Anderson, M.L. and R.L. Purple. Circadian rhythms and variability of the clinical electrooculogram (EOG). Invest. Ophthal. Vis. Sci. 19:278-288.

70. Dufresne, J.F., J.F. Soechting and C.A. Terzuolo. The utilization of myotatic feedback in motor control. Tutorials in Motor Behavior, ed., G.E. Stelmach. In press.

71. Anderson, J.H., J.F. Soechting and C.A. Terzuolo. Role of vestibular inputs in the organization of motor output to forelimb extensions. Prog. Brain Res. 50:413-421.

72. Berthoz, A., M. Lacour, J. Soechting and P.P. Vidal. The role of vision in the control of posture during linear motion. Prog. Brain Res. 50: 197-210.

73. Dufresne, J.F., J.F. Soechting and C.A. Terzuolo. Reflex motor output to torque pulses in man: identification of short and long latency loops with individual feedback parameters. Neurosci. 4:1493-1500.

74. Viviani, P. and C.A. Terzuolo. Space-time invariance in learned motor sequences. Tutorials in Motor Behavior, ed., G.E. Stelmach. In press.

75. Terzuolo, C.A., J.F. Soechting and J.R. Dufresne. Adaptive properties of the myotatic feedback. Prog. Brain Res. 50:69-75.

76. Robles, S.S. and J.F. Soechting. Dynamic properties of cat tenuissimus muscle. Biol. Cybernetics 33:187-197.

77. Pappas, C. and J.H. Anderson. Effect of midbrain lesions on vestibulo-neck reflexes. Soc. Neurosci. Abst. 5.

78. Fohlmeister, J.F. A theoretical study of neural adaptation and transient responses due to inhibitory feedback. Bull. Math. Biol. 41:257-282.

79. Soechting, J.F. and J.F. Dufresne. An evaluation of nonlinearities in the motor output response to applied torque perturbations in man. Biol. Cybernetics 36:63-67.

80. Dufresne, J.F., J.F. Soechting and C.A. Terzuolo. Modulation of the myotatic reflex gain in man during intentional movements. Brain Research. In press.

81. Quick, D.C., W.R. Kennedy and R.E. Poppele. Anatomical evidence for multiple sources of action potentials in the afferent fibers of muscle spindles. Neurosci. 5:109-115.

82. Fohlmeister, J.F., W.J. Adelman and R.E. Poppele. Excitation properties of the squid membrane and model systems with current stimulation: statistical evaluation and comparison. Biophys. J. In press.

83. Fohlmeister, J.F. Electrical processes involved in the encoding of nerve impulses. Biol. Cybernetics 36:103-108.

84. Dawis, S.M. Steady-state adaptation in cone receptors. Ph.D. Thesis, University of Minnesota.

APPENDIX II. Laboratory Staff

R.E. Poppele, Professor and Director

C.A. Terzuolo, Hill Professor

R.L. Purple, Professor

C.K. Knox, Associate Professor

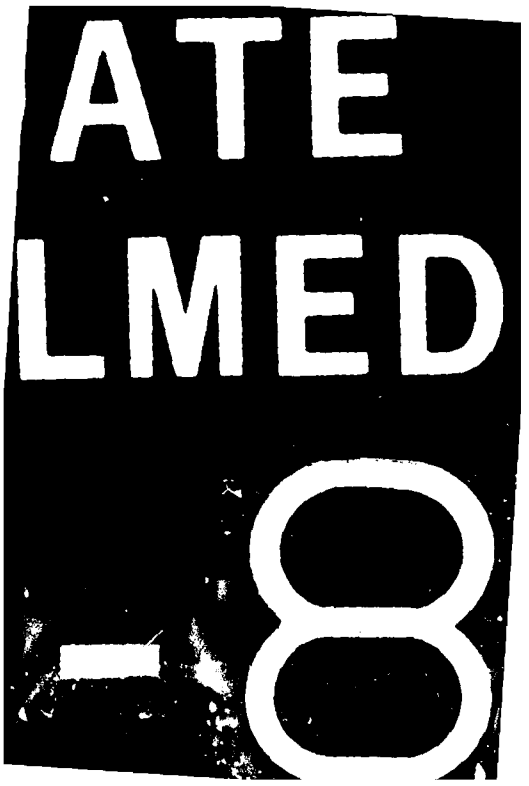
J.F. Soechting, Associate Professor

J.F. Fohlmeister, Assistant Professor

Fellows:	Degree Awarded	Date
John Anderson	M.D., Ph.D.	1973, 1976
Joel Dufresne	Ph.D.	1977
Gary King	Ph.D.	1979
Stephen Dawis	Ph.D.	1980
Fay Horak	M.S.	1977
Sofia Robles	M.S.	1978
Stephen Holloway	M.S.	1976
Deborah MacNeill	--	--
Michael Anderson	M.D.	1979

Paulo Viviani, Visiting Fellow

Constantinos Pappas, Visiting Fellow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