Motor Learning

The Acquisition of Motor Behavior in Vertebrates. JAMES R. BLOEDEL, TIMOTHY J. EBNER, and STEVEN P. WISE, Eds. MIT Press, Cambridge, MA, 1996. xii, 440 pp., illus. $65 or £55.50. ISBN 0-262-02404-7. From a meeting, Key West, FL, April 1995.

Motor learning can be defined as a set of neural processes associated with practice that lead to changes in performance and capabilities. Earlier studies of the process, reviewed by Stelmach in this volume, focused on behavioral aspects and on determining optimal practice strategies. In contrast, the present book focuses on the fundamental questions of which features of motor behaviors are learned and the underlying neural mechanisms of motor learning, as studied in vertebrates. Comprising 20 chapters by 39 authors, it reflects the interdisciplinary nature of current motor-learning research and includes broad and illuminating surveys of studies using different experimental techniques (such as neural recording or functional brain imaging) and theoretical models.

The picture of motor learning that emerges from the book is one of a highly distributed system, comprising several brain structures and interconnected neural networks. These structures include different cortical regions, the cerebellum, the basal ganglia, and various brainstem nuclei. Whereas another recent book on motor learning, edited by Houk *et al.* (MIT Press, 1995) focused on the role of the basal ganglia, this one focuses mainly on the cerebellum and cortical areas.

Examples of motor learning ranging from adaptation of gains of relatively simple reflexes to more complicated behaviors are discussed. These examples suggest that certain distinctions can be drawn regarding the involvement of brain structures. The cerebellum seems to be mostly involved in motor adaptation and coordination, combining different elementary movements into compound movements, and the motor cortex seems to play a larger role in the acquisition of new skills and possibly in the shaping and tuning of the elementary movements.

Three chapters (by Lisberger, by Baker and Gilland, and by Horak) deal with reflex adaptation in the vestibuloocular reflex (VOR) and postural reflexes. Similarities between learning in the VOR and classical conditioning support the role of the cerebellum in motor learning (see Raymond *et al.*, *Science* **272**, 1126 [1996]). Several chapters review ablation studies that suggest that the cerebellum is necessary both for learning in the VOR and for classical conditioning. However, in both cases (as discussed by Lisberger and by Bracha and Bloedel) ablation of the pertinent parts of the cerebellar cortex and deep nuclei removes only part of the memory acquired in previous training although it prevents further learning, suggesting the existence of multiple memory sites.

Not all the contributors agree that the cerebellum plays a central role in motor learning. Steinmetz argues that the network involved in eye-blink conditioning is widely distributed. An even more extreme view is expressed by Harvey and Welsh, who point to the importance of the cerebellum in the optimal execution of motor tasks but not necessarily in learning. Other interesting chapters in this section include that by Disterhoft *et al.* on the possible involvement of hippocampal neurons in trace eye-blink conditioning. Woody describes the mechanisms responsible for the increased probability of conditioning-evoked discharge in motor cortical cells that selectively project to muscles involved in generating the conditioned responses.

The picture is less clear when it comes to synthesizing our current knowledge with respect to learning in the context of visually guided movements and sequential tasks. A review by Thach examines the possible role of the cerebellum in eye-hand coordination (as in pointing) and in calibrating internally represented visual-motor transformations (as in dart-throwing while wearing distorting prisms). Thach concludes that the available data support the Marr-Albus theory, and he extends it to learning of complex movements. He suggests that commands for movements involving different body parts and multiple muscle synergies might be synthesized by combining lower motor elements through the contacts of unique subsets of parallel fibers with many Purkinje cells through synapses, adjusted by climbing-fiber activity. Ebner *et al.* review cerebellar studies of patients and healthy subjects in which functional imaging techniques have been used. They stress the importance of distinguishing between deficits in performance and deficits in learning in cerebellar impairments.

Several authors emphasize the importance of other cortical and subcortical sites for learning of sequential motor tasks. Hallett *et al.* suggest that the motor cortex may have a much greater role than the cerebellum in new skill acquisition (that is, learning what to do as distinct from how to do). Wise discusses the evidence for the hypothesized role of the premotor cortex and basal ganglia in the ability to develop rapidly changing stimulus-response relationships (conditional learning). Hikosaka *et al.* investigate whether procedural learning and memory have common or distinct neural mechanisms. Soechting *et al.* compare possible organizing principles for typing and for piano-playing movements. More coarticulation between different movement segments is observed in piano-playing.

Several chapters emphasize future research perspectives, including a discussion by Stelmach of the importance of transfer tests to determine when learning is specific and when it is more general or abstract. Donoghue *et al.* review possible cellular and neural mechanisms (including long-term potentiation) for learning by cortical cell assemblies, and the reorganization occurring in motor maps. Asanuma discusses possible motor-output selection based on experience as demonstrated in studies involving electrical stimulation within the somatosensory cortex that induced long-term potentiation in the corticocortical projections to the motor cortex. Kawato reviews current computational models of cerebellar motor learning. He hypothesizes that the cerebellum is a site of storage and adaptation of internal models of the controlled body parts and of the environment.

The book is a timely contribution to this rapidly evolving field. It will be of interest to those directly involved in motor-control research as well as to researchers and students who wish to understand motor function.

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Browsings

Implicit Cognition. Geoffrey Underwood, Ed. Oxford University Press, New York, 1996. xii, 305 pp., illus. $80 or £45, ISBN 0-19-852311-4; paper, $35 or £19.95. ISBN 0-19-852310-6.

Seven papers exploring behavior influenced by information that is not available to consciousness, with a concern for describing the relation between consciousness and cognition; topics include unconscious influences of memory, task and process dissociation, implicit learning, and intuition in problem-solving.

The Large, the Small and the Human Mind. Roger Penrose, with Abner Shimony, Nancy Cartwright, and Stephen Hawking. Malcolm Longair, Ed. Cambridge University Press, New York, 1997. xviii, 185 pp., illus. $19.95 or £14.95. ISBN 0-521-56330-5.

The author of *The Emperor's New Mind* and *Shadows of the Mind* (see *Science* **248**, 880 [1990] and **266**, 1737 [1994]) gives an updated version of his views and responds to challenges by two philosophers and the author of *A Brief History of Time*.