work by David Randall and his colleagues suggests that extraction of oxygen from air is commonplace among diverse aquatic vertebrates; the "unique event" was the reassignment of the regulatory and excretory functions of gills to other structures when gills were lost.

This book reviews the specializations of some amphibious vertebrates (fishes, amphibians, reptiles) for regular "metering out" of oxygen to the tissues during submergence and effective ventilation at the water's surface when submergence ends. As the authors emphasize, this is not a simple matter of the animal's holding its breath. Submergence necessitates an intricate concatenation of changes in heart rate, distribution of cardiac output, and blood and lung gas concentration, all in phase with an irregular rhythm of breathing. The review is not merely a catalogue of unrelated facts. Its purpose is to document parallel evolution, that is, how different vertebrates use diverse structures, behaviors, and regulatory systems to achieve very similar patterns of air breathing.

A second theme is the physiological adjustments that evolution of air breathing entails and deserves special emphasis here. Randall *et al.* suggest that evolution of aerial oxygen uptake was a relatively routine matter for vertebrates. For example, fish and amphibians have elaborated such diverse structures as gills, lungs, the swim bladder, the mouth, the pharynx, the suprabranchial chamber, the operculum, and even the gut as aerial gas exchangers. Such specializations occur in many vertebrates that exploit aquatic environments in which oxygen is scarce.

In hypoxic aquatic environments, however, fish readily lose oxygen to the water through their gills. Hence gills may be a liability in such environments, and are reduced or lost in many lineages. Yet evolutionary loss of aquatic gas exchangers probably posed major difficulties. As Randall *et al.* point out, the gills of fishes regulate concentrations of diverse ions, especially hydrogen ions, and are the major organ of carbon dioxide excretion. Coupled with these roles are specializations in the enzyme carbonic anhydrase, relatively sluggish circulation, and regulation of plasma pH via bicarbonate concentration (rather than carbon dioxide concentration as in mammals). Therefore loss of gills necessitated major changes in many systems, and also in the way vertebrates inspire air. Randall *et al.* speculate that ion homeostasis and carbon dioxide excretion were allocated to the skin in amphibians and in those fishes that have reduced gills, which restricts them to aquatic environments (but see below). Only when lungs and specialized osmoregulatory organs assumed these functions could vertebrates become fully terrestrial.

Both specialists and nonspecialists with knowledge of introductory physiology should find this book fascinating. Chapters on gas transfer, ventilation-perfusion relationships, mechanisms of ventilation, and regulation of gas exchange begin with simple explanations of general principles and then proceed into lucid discussion of primary data. Abundant figures and some spectacular photographs of respiratory structures add clarity. Many sections are speculative, but the speculation is presented as such and is provocative. My single complaint is that the authors neglect the diversity and success of nonpiscine vertebrates that are able to breathe both air and water. Salamanders, larval amphibians, turtles, and marine snakes are not discussed. In particular, the authors characterize amphibians as largely restricted to aquatic environments, even though many are completely terrestrial.

All too often comparative physiologists document obvious differences among organisms and then tell stories about the adaptive significance of these differences. Randall *et al.*, by contrast, align seemingly disparate aspects of vertebrate physiology into a cohesive whole and suggest novel consequences of this alignment. This book raises important issues and may well shape future research efforts in comparative vertebrate physiology.

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Mechanisms of a Response

Estrogens and Brain Function. Neural Analysis of a Hormone-Controlled Mammalian Reproductive Behavior. DONALD W. PFAFF. Springer-Verlag, New York, 1980. x, 282 pp., illus. $24.90.

Behavioral biology is one of the most fragmented of all scientific disciplines because most behavioral scientists restrict themselves to a single level of analysis. However, the most significant advances in our understanding of the biological bases of behavior have come about when several levels of analysis are combined into a single research program. Donald W. Pfaff is one of the foremost practitioners of this approach.

In *Estrogens and Brain Function*, Pfaff moves effortlessly from the organismal to the molecular in an analysis of the lordosis behavior of the female rat. Using the analogy of the reflex arc, he guides the reader through an extraordinary research program that has traced the sequence of events underlying this hormone-dependent behavioral response, including the manner in which stimuli are perceived and integrated in the central nervous system and the way in which this information is influenced by the female's hormonal milieu.

Beginning with a description of the dynamics of the sexual encounter, Pfaff shows how the behavior of the male elicits postural changes in the female, ultimately resulting in the exhibition of lordosis. Stimulation of specific areas of the female's body, particularly the flanks, tail base, and perineum, are crucial for the occurrence of lordosis. The sensory nerves supplying the perineal skin enter the spinal cord, converging onto spinal interneurons. Recordings of single units in the dorsal-root ganglion indicate that each hair or hair-skin unit is activated by one type of hair, whereas at the level of the spinal gray many units respond to both hair movement and skin deformation and other combinations of cutaneous stimulation. Transection of different regions of the spinal cord demonstrates that the anterolateral columns are the critical ascending neural pathway, projecting into the central gray of the midbrain.

Estrogen has profound effects on both the peripheral and the central nervous systems. The sensitivity of the peripheral mechanoreceptors and the receptive field size of the pudendal nerve increase with estrogen treatment in ovariectomized females. Further, estrogen is taken up and bound in specific regions of the brain, including the medial preoptic area (POA), the medial anterior and basal hypothalamus, the limbic system, and the mesencephalon.

The hypothalamus is a major integrative area, and it is here that we see the pivotal role played by estrogen. Pfaff shows how estrogen increases biosynthetic and secretory activity of cells in the ventromedial hypothalamus and increases electrical excitability of medial anterior and basal hypothalamic neurons. Lesions in the medial anterior hypothalamus and ventromedial nucleus (VMN) of the hypothalamus result in severe deficits in lordosis behavior. This effect is transitory, however, indicating that these cells are not part of a direct reflex arc but influence the descending brainstem pathways that facilitate lordosis. In complementary studies, electrical stimulation of the VMN facilitates lordosis in estrogen-primed, ovariectomized females. Interestingly, estrogen treatment decreases electrical activity of POA neurons and lordosis performance is increased following POA lesions but is inhibited when the POA is stimulated. These apposing actions of the VMN and the POA serve to regulate female sexual receptivity.

Pfaff next traces the neuronal projections from the VMN and POA to the mesencephalic central gray, describing how axons descend through the hypothalamus and medial forebrain bundle in layers. Electrical stimulation of this area facilitates lordosis behavior whereas lesions abolish it. Descending fibers exit the central gray, projecting to the reticular formation of the lower brainstem. The hormone-dependent hypothalamic output signals that are transformed and relayed in the central gray are carried in the lateral vestibulospinal and reticulospinal tracts, terminating in the spinal cord. Lesions of these descending pathways disrupt lordosis behavior whereas stimulation of the lateral vestibular nucleus, the source of the lateral vestibulospinal tract, facilitates it. The final common pathway, the motoneurons controlling the muscles responsible for elevating the rump, the most crucial component of the lordosis behavior, is located in the medial and ventral borders of the ventral horn.

This analysis of the neural circuitry of lordosis behavior, which forms the major portion of the book, is followed by a discussion of its implications for neuroscience and related fields of behavioral research. Though providing much insight for the former, Pfaff is not always successful as he moves outside the boundaries of the neural control of behavior. He relies on dated ethological concepts, such as Lorenz's hydraulic model, and ignores recent advances in behavioral biology. Another disappointment is the lack of incorporation of relevant research from other laboratories. Although a plausible theory of the central mechanisms that differentiate male from female sexual behavior is presented, there is no consideration of sex differences in brain structure and function.

These are minor complaints, however. *Estrogens and Brain Function* is a well-written and authoritative account of one of the outstanding research programs in neuroscience. It undoubtedly will be a model for future analyses of the physiological mechanisms of motivation.

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The Biophysical Substrate

Molluscan Nerve Cells. From Biophysics to Behavior. Papers from a meeting, Cold Spring Harbor, N.Y., May 1980. JOHN KOESTER and JOHN H. BYRNE, Eds. Cold Spring Harbor Laboratory, Cold Spring Harbor, N.Y., 1980. xx, 230 pp., illus. $26. Cold Spring Harbor Reports in the Neurosciences, vol. 1.

In the study of the physiology of excitable (nerve and muscle) membranes a quiet revolution has taken place in the last five years. The conductances through which membrane currents flow have been shown in some cases to be quantized, or made up of irreducible units of 2 to 30 picosiemens. These conductance steps represent the opening and closing, many times per second, of single ionic channels whose molecular properties are just beginning to be understood. In addition, the roles of intracellular calcium and hydrogen ions are being actively studied, and both are proving to have strong effects on cellular function. Some recently discovered potassium currents are strongly implicated in the process of rhythmical firing and "burst" or grouped discharges, and these and some calcium currents affect the control of some simple behaviors. All of these topics are covered in this delightful new collection of brief reports.

The book is made up of transcriptions of talks given at a meeting organized by C. F. Stevens and E. Kandel. One purpose of the meeting was to stimulate interaction between investigators of membrane biophysics and of neural control of behavior. The rationale for this was that "it is now possible to relate the biophysical properties of individual neurons to the features of the behavior that they mediate." Whether the organizers' goal was in fact reached is dubious, but the reports are concise and informative and cover the latest developments in each subdiscipline. Most of the work described was done on molluscan neurons, which are generally spheroidal and large (100 microns or more in diameter) and which survive well in vitro and tolerate multiple impalements with microelectrodes.

The foreword by J. D. Watson contains an absorbing history of the neuroscience programs at Cold Spring Harbor Laboratory. These include important meetings on neurons in 1952, at which the Hodgkin-Huxley model of excitation was widely discussed, on sensory receptors in 1965, and on synapses in 1975, all resulting in well-organized and important contributions to the literature. A historical chapter by Kandel places the recent work in context, and Stevens attempts the feat of reviewing all the techniques used in the present studies in 21 pages, without illustrations (which he does with some success). The book is not for the completely uninitiated, however.

The biophysical material, 17 of the 19 reports, is presented in accessible chunks seven to ten pages in length. These give the news but do not overtax. A general summary of properties of calcium channels (Hagiwara) contains a caveat for the use of preparations such as barnacle and heart muscle or presynaptic terminals where perfect space-clamp of membrane potential is not possible but where important information can be obtained under appropriate conditions. The inactivation of calcium channels by accumulation of intracellular calcium is documented in a sparkingly clear way (Tillotson). The single-channel conductance of calcium channels is shown to be much lower than that of sodium or potassium channels, perhaps as little as 0.2 picosiemens (Brown). A probabilistic model of calcium currents in presynaptic terminals (Llinás) gives a good representation of pre- and postsynaptic events in the squid giant synapse. The interactions of sodium, potassium, and hydrogen ions are such that nerve cells placed in sodium-free solutions will be less able to regulate their intracellular pH (Thomas). Calcium buffers in squid axons can bind 99.95 percent of an artificially introduced calcium load (Brinley). A potassium conductance that is activated by elevations of intracellular calcium is discussed with respect to which divalent ions stimulate it most strongly (Meech) and how it is affected by membrane potential (Lux). Some updated models are presented for calcium regulation (S. Smith), potassi-