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Regulatory Systems in Neuroscience and Biobehavioral Psychology

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There is increasing public interest in neuroscience. Particular attention is paid to the cognitive, motor, and sensory systems, and their pathologies. But staying alive requires much more from our neurons. The mechanisms by which the brain and spinal cord control the basic life-sustaining functions are classified as regulatory. These include the neuronal networks that govern cardiovascular, respiratory, thermoregulatory, and gastrointestinal functions; hormone release from the various endocrine organs; energy and water balance; the sleep/wake cycle; growth, reproduction, responses to stress; and all the associated behaviors. Such processes are subject to little, if any, voluntary control, and in most cases we remain unaware of their status—conspicuous exceptions include blushing, sweating, sexual arousal, and hunger. “I didn’t realise the brain does that” is a familiar comment about many of the regulatory processes.

Whatever takes place within the central nervous system, all ensuing outputs depend on muscle activity or hormone release. These are the sole means by which the brain and spinal cord can act beyond their bony casings. Stephen Hawking’s thoughts would remain private without his residual control of a cheek muscle and the technology to which it is linked. For the regulatory systems, the muscle-mediated functions that can be seen externally range from simple reflexes, such as shivering, to elaborate appetite-driven sequences of behavior. In contrast, neuromuscular effects on blood flow are visible only when the vessels are superficial. For the brain’s control of hormone release—whether indirectly via the anterior pituitary gland or directly from the posterior pituitary gland or adrenal medulla—there are fewer outward signs. Visible indications of neuroendocrine activity include the onset of puberty and milk ejection.

A vast range of signals reach the brain from other parts of the body and beyond the body. For many regulatory systems, the principal signals entering or leaving the brain are blood-borne (Coen, 2015). Selected peptides gain entry through active transport mechanisms, but steroids, being lipophilic, enter by free diffusion. Vanishingly few cerebral functions are impervious to the endocrine environment. To distinguish the short-term and lifelong effects of blood-borne factors, the concept of activational and organizational effects was introduced. In some neuronal networks, permanent reorganization occurs if a particular steroid is circulating above a critical concentration during a specific period in development. Such processes establish sex differences in brain anatomy. Similar organizational effects occur when psychological stress or excessive nutrition is experienced early in life.

Many of the adjustments made by the regulatory systems, such as those associated with reproduction, are not classically homeostatic. Nevertheless, homeostasis—maintenance of a constant internal environment despite external changes—has been one of the important paradigms in the development of regulatory neuroscience (McEwen and Wingfield, 2010). But any simple analogy with thermostats is misleading. Being hyperthermic or dehydrated is not a prerequisite for drinking; adaptive behavior is often anticipatory. Homeostatic set points—targets for the regulatory systems—are useful as a concept only if their shifting nature is recognized. The task of keeping all the regulatory factors at an adaptive level is ultimately a matter of life and death. Throughout recorded history our sense of mortality has been dominated by just two of those factors: breath and pulse.

Because of their daily or seasonal periodicity, some of the challenges to physiological equilibrium are predictable. Evolution on a planet that rotates on a tilted axis has led to processes that adjust the set points accordingly. Such adjustments depend on a remarkable example of biological constancy within the source of so much change, the circadian clock: compensatory mechanisms ensure that the molecular biological and biochemical processes on which the stability of the clock depends are not disrupted by the body temperature oscillations driven by that clock.

In addition to their neuromuscular and neuroendocrine outputs, the regulatory systems have certain effects that remain firmly within the cranium. The sleep/wake cycle includes neurophysiological changes associated with entirely private experiences such as dreaming or regaining consciousness. There are many unanswered questions about the process—ultimately irresistible—that renders us unconscious and even paralyzed for a substantial proportion of our life. The full biological significance of this cycle is still obscure, as are some of its basic features. For example, the survival value of being nocturnally or diurnally active may be clear, but the neuronal mechanisms that distinguish species in this binary way are unknown.

Characterizing the neuroanatomy and neurochemistry of the networks that form the regulatory systems is a major objective in regulatory neuroscience. But quests to identify governing centers are confounded by the problem of primacy—the chicken and egg problem: no particular component seems to be in charge, as shown by the continuing discovery of networks with modulating and feedback functions. The only part of the brain that accomplishes *in vitro* the full function that it accomplishes *in vivo* seems to be the suprachiasmatic nucleus: it continues to generate circadian rhythms whether connected to or isolated from its targets. But this self-contained function is barren if it lacks integration into the neuronal networks of the regulatory systems. These networks are predominantly distributed across the hypothalamus and brainstem, regions that are fittingly noted for their neuroanatomical and neurochemical heterogeneity (Thompson and Swanson, 2003).

As concerns grow about our stewardship of the global environment, it seems timely to draw attention to the neuronal systems that keep our internal environments functioning. These lifeguarding systems are comprehensively covered in the Regulatory Systems section of the *Reference Module in Neuroscience and Biobehavioral Psychology*. The articles, which have been designed for a wide readership, show that regulatory is a term denoting much more than basic housekeeping. The regulatory systems are essential not only for the life of the individual and the survival of the species, but also for the capacity to flourish in a wide range of environments. Such features make this field of research particularly exciting and fundamentally important for our understanding of health and disease.

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