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The Cognitive Neurosciences, Fifth Edition

Introduction

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My first thought when Mike Gazzaniga and Ron Mangun asked me to be the editor for this section of this book was: “What do I know about plasticity and learning?” My second thought was: “Aren't they the same thing?” This motivated a venture to the dictionary, where I looked up the definition of both terms.

Learning: the acquisition of knowledge or skills through experience, study or by being taught. (The New Shorter Oxford English Dictionary)

Plasticity: the quality of being plastic; especially: capacity for being molded or altered. (Merriam-Webster)

Although a variety of definitions are found for both terms, the most common definitions of learning emphasize experience and repetition, while those for plasticity emphasize the capacity to change. If our underlying assumption is that behavior in all animals is mediated by the brain, and the covert behavior of acquiring new information through exposure and repetition requires the capacity to change the brain, then brain plasticity and learning are inextricably interwoven, but not the same thing. It is possible that the extent to which the brain, particularly the neocortex, is plastic distinguishes mammals from each other, and that the mechanisms that generate plasticity evolve. Thus, while the ability to be plastic may be genetically determined, the actual changes to the phenotype are context-dependent. Such changes can appear to be hereditary, masquerading as evolution, when in fact a stable developmental environment is merely triggering the same plasticity in each new generation.

I began my research career trying to understand how complex brains evolve, and quickly realized how restricted this question was. Evolution deals with heritability, and therefore only the genetic component of the phenotype. What I grew to appreciate was that the important question was how complex phenotypes emerge. This deals with both genetic, heritable traits as well as traits that are context-dependent. Every given species is a combination of both, and any individual within a species could have a multitude (or at least a broad distribution) of phenotypes of brain organization and behavior that are expressed in varying environmental contexts. Thus, evolution and plasticity are also intertwined.

The focus of this section, “Plasticity and Learning,” is the neocortex, the portion of the brain associated with volitional motor control, perception, and higher cognitive processing. Collectively, this section spans many levels of organization. When considering how the neocortex works and how it changes within the lifetime of an individual and across species over time, it is important to recognize that the neocortex is only one component of the entire nervous system. It should be obvious, but it is valuable to remember that the nervous system is embedded in a body that has sensory receptor arrays and a particular morphology that is often highly derived. For example, a bat interacts with the world in a very different way than a monkey. Each have different forelimb morphologies, a wing versus a hand, and each have enhanced sensory receptor arrays that allow for extraordinary abilities associated with the auditory (sonar) versus the visual (form vision) system, respectively. The cortical areas that process inputs from these specialized effector arrays have expanded and are specified by their unique inputs, and additional fields have been added to the portions of the neocortex that ultimately receive inputs from these sensory systems. Further, cortical networks necessary for sensory motor integration for flight versus manual dexterity, and for interfacing the specialized effectors (ears/pinna versus eyes) with the object to be explored are also uniquely wired within the brain. Finally, each body faces a different and changing physical environment, areal versus terrestrial-arboreal, that constrains movement and perception.

This body/brain configuration of a given individual within a species interacts with other bodies and brains, chasing, courting, mating, attacking, fleeing, communicating, and forming social systems. These individuals interact with other species and other social systems in a variable physical environment composed of living and nonliving elements. This group of organisms and their environment generates a complex and highly dynamic collective biomass that has emergent properties that differ from, and often exceed, the individual parts of which it is composed. For example, a social system has properties that cannot be easily explained by the behavior of a single individual, or brain, or neural firing pattern.

On the other end of the spectrum, brains can be decomposed into cortical networks, made up of nodes or cortical areas, which are composed of local neural circuits. These circuits are formed by neurons, which are held together by the cytoskeleton and plasma membranes and connected to each other by synapses. These in turn include smaller elements such as synaptic receptors, which are composed of molecules encoded by genes, and the expression and transcription of genes can be controlled by environmental context. While genes are the heritable part of this complex hierarchy, it is the larger, often context-dependent components of organization, such as behavior, that are the targets of natural selection. To further complicate matters, the relationship between the targets of selection and genes is often correlative and generally indirect.

Keeping these different levels of organization in mind, the authors of this section were charged with addressing several important questions. What is changing in the neocortex, and does it directly or indirectly co-vary with the target of selection, which in this case is the ability to learn and respond appropriately in a complex and dynamic multisensory context? At what level should we be looking for these alterations in the neocortex? Will there be changes in the microcircuitry (Rodney J. Douglas and Kevan A. C. Martin) and/or the macrociruitry (Olaf Sporns)? How does enhanced or degraded input from our sensory receptor arrays affect the functional organization of the brain and our perceptions of a sensory experience (Jon H. Kaas and Charnese Bowes)? Do particular types of neocortical organizations promote plasticity (Man Chen and Michael W. Deem)? What is the impact of groups of brains (social systems) on the development of brain structure and function (Courtney Stevens and Helen Neville), and how does the brain change throughout the entire life of an individual (Gregg H. Recanzone)? What are the underlying mechanisms that generate these phenotypic alterations at all levels of organization (Tania Roth), from cellular to systems levels, and how do these changes result in variant behaviors? The objective of addressing these questions is to begin to understand the boundary conditions of each level of organization; how higher levels of organization emerge from and interrelate with lower levels; how the brain dynamically generates highly adaptive, context-dependent behaviors throughout a lifetime; and how human social and cultural evolution impact brain evolution.