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Preface: Current Opinion in Neurobiology — Cognitive Neuroscience 2010

Editorial overview

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Much of our understanding of the brain is modular. Investigation has necessarily focused on its individual parts' regions at different levels of analysis (e.g. individual neurons and brain areas), in part because that understanding the parts is a prerequisite to understanding the whole, and in part because of historical limitations inherent in our tools of investigation. But recent years have seen a rise in approaches designed to gain a more integrative understanding of the brain as interacting networks of neurons, areas, and systems. Functional neuroimaging has allowed big pictures of activity throughout the human brain. This permits direct comparisons of patterns of activation across many brain areas simultaneously and, by examining coherent fluctuations in blow flood, identifies putative large-scale, brain-wide, networks (e.g. [1]). There has also been the rise of large-scale multiple-electrode neurophysiology, the implantation of up to 100 or more electrodes, often in multiple brain structures. This allows comparisons of neuron populations in different brain areas that are not confounded by extraneous factors (differences in level of experience, ongoing behavior, etc.) as well as measurements of the relative timing of activity between neurons that give insight into network properties [2]. This growth in integrative approaches is technically and conceptually driven. Many investigators are employing the classic techniques of systems neuroscience (e.g. single-electrodes, microstimulation, and pharmacology) to compare and contrast brain areas and test how they interact. In short, neuroscience is increasingly building on our knowledge about the brain's parts to begin to put them together.

Our goal with this special issue was to highlight integrative approaches to brain function. To this end, we focused on the most integrative of brain functions, cognitive control. Cognitive, or executive, control is the ability to coordinate thought and action by directing them toward goals, often far-removed goals. Thus, by definition, cognitive control involves coordination of multiple brain mechanisms across multiple brain areas and systems. We chose investigators who are addressing how cognitive control results from networks of interacting neurons, areas, and systems.

One area of increasing interest is neural oscillations, coordinated rhythmic activity of large numbers of neurons. There is mounting evidence for its role in cognition, as reviewed in several papers in this issue. Duzel *et al.* discuss the role of gamma and theta rhythms in encoding, consolidation, and retrieval of memories. Jutras and Buffalo also highlight memory formation and outline how gamma and theta rhythms and their interactions in the medial temporal lobe support the processes underlying learning at the cellular level. Engel and Fries focus on beta-band (13–30 Hz) oscillations.

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They forward the intriguing hypothesis that beta-band activity seems related to the maintenance of the status quo, the current sensorimotor, or cognitive state. Pesaran reviews the role of oscillations in decisions and voluntary actions, specifically in how coherent oscillations between distant brain areas may reflect their linking and interacting during control of behavior. Schroeder and colleagues argue for Active Sensing: that the brain rhythmically samples the external world and entrains its own rhythms to them. One of the hallmarks of higher cognition is its severe limitation in capacity; we can only think of a very limited number of items simultaneously. Fukuda *et al.* review this phenomenon and discuss how it may be because of oscillation-based coding.

Other reviews focus on interactions between brain areas and how information may flow between them. Noudoost *et al.* review evidence that top-down attention signals acting on visual cortex originate from brain areas involved in eye movement control. One area of investigation where study of the interaction of brain areas is increasingly common is the representation of value and several of the reviews touch on this topic. Wallis and Kennerley note that reward signals are present throughout the frontal lobe, but by comparing and contrasting brain areas they suggest relatively distinct roles for the orbital, lateral, and cingulate prefrontal cortex. Kehagia *et al.* survey research from a range of techniques and across species to explore the interaction of the striatum and prefrontal cortex in enabling flexible adaptation to changing reinforcement contingencies. Schoenbaum and Esber argue that the key function of the orbitofrontal cortex is to integrate information from other brain regions, such as the amygdala and striatum, to signal expected outcomes. The interaction of the amygdala and orbitofrontal cortex is also highlighted in the review by Murray and Wise, which discusses the unique and complementary roles of these regions in representing and updating stimulus value. In a similar vein, Morrison and Salzman discuss the role of the amygdala in representing stimulus valence and compare it to the orbitofrontal cortex. Sotres-Bayon and Quirk suggest that regulation of fear requires the control of the amygdala by other prefrontal regions, specifically the infralimibic and prelimbic cortex, Sommerville and Casey explore cognitive control to incentives across the lifespan and argue that there are windows of development, namely adolescence, where cognitive control is more vulnerable because of the pattern of development of different components of the coricostriatal circuitry. One commonality in all these reviews is that they highlight how interactions among brain systems are necessary to control and adapt behavior in complex and changing environments. Finally, Braver *et al.* discuss the neural infrastructure that explains individual differences in executive control. This issue has been rarely addressed; most investigators treat individual differences as ''noise'' not as a topic of investigation. Yet, we are all individuals.

Finally, the interactive approaches highlighted in this issue benefit from computational models of the brain, which often provide the theoretical 'glue' that ties multiple observations together and make further predictions. Niv and Gershman argue that simple reinforcement learning models cannot fully capture many complex situations. They discuss how to integrate structure learning and reinforcement learning to more accurately model decision-making and behavior. O'Reilly *et al.* outline computational models of cognitive control that explore the interactions of the prefrontal cortex with other brain areas to allow task relevant processing in the face of distractions and interference. Rangel and Hare discuss the computations underlying goal-directed choices and, by reviewing both FMRI and neurophysiological studies, how those computations may be implemented in the brain.

As the reviews in this issue illustrate, this shift in approaches to studying brain function as interactive networks creates an additional, but necessary layer of complexity in our efforts to capture the neural mechanisms of cognition and behavior. Cognitive neuroscience is a field that is built on the principle of integration. The early days of cognitive neuroscience emphasized the integration of techniques, combining insights from cognitive psychology, neuroscience, and computer science. This integrative approach was quite successful. This combination of techniques is represented in every prominent program of the study of behavior today. As cognitive neuroscience progresses, however, the focus is shifting to another level of integration — the combination of processes across levels of analysis and systems in the brain. We hope this special issue has helped highlight some of the ways this new level of integration can advance future research in cognitive neuroscience.

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