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Cognitive neuroscience

Editorial overview

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The author's laboratory studies the neural basis of learning and decision-making using a combination of techniques from neuroscience, economics and psychology. Behavioral studies of decision-making in both human and non-human primates guide physiological experiments using single neuron recording and functional magnetic resonance imaging. The goal of the laboratory is to achieve an interdisciplinary understanding of choice behavior that transcends the understanding of this phenomenon available to any single scholarly discipline.

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The author's laboratory studies high-level vision in humans by exploring the functional organization of the brain regions that carry it out, as well as by studying the cognitive and neural processes conducted in each of those regions.

Introduction

For the past century and a half both physiologists and neurologists have dissected, probed, recorded from and stimulated the mammalian nervous system with one central goal: to understand how our brains make us who we are. The first hundred years was marked by the steady accretion of theory and evidence from both of these groups: physiologists seeking to describe the cellular foundations of neural function, and neurologists seeking to describe the relationships between cognitive function and gross damage to the organ of behavior. What we believe has spawned the explosive growth of cognitive neuroscience in the past decade is the fact that now, for the first time, these two approaches have begun to meet in a uniquely fertile manner. What we hope this *Current Opinion in Neurobiology* issue makes clear is that the micro-foundations of neural function are now being used to understand the macroscopic structure of behavior in a way that has never before been possible.

As a result, the articles in this issue summarize recent advances that range from functional studies of social cognition to physiological studies of strategic decision-making. Of course the challenge that such a diverse set of inquiries poses for editors is how to organize them into a coherent sequence of articles that both captures the synthetic breadth of cognitive neuroscience today and respects the pre-existing subdisciplines from which this synthesis arises. The usual response to that challenge is to begin with articles on sensory issues in cognitive neuroscience, to proceed through decision-making, and perhaps memory, to motor neuroscience. After having encapsulated the classically defined subdisciplines of the sensory–motor stream in this way, the really exciting material, the 'cognitive' cognitive neuroscience, so to speak, gets bundled together in a final section. Employing this approach is almost unavoidable at this point in the history of brain science (and so we do employ it here), but we believe that neurobiologists must push themselves to recognize the perils of these old divisions. What this traditional format obfuscates is the simple fact that the 'higher-order' functions of the nervous system, cognitive cognitive functions, govern behavior every bit as much as do sensory and motor processes. As the traditional sensory–motor view of physiologists fuses with the cognitive methodologies of neurologists and psychologists, it becomes clear that even the simplest of behaviors is the coherent synthesis of many interacting subsystems. Gone are the days when physiologists could dismiss cognitive functions as irrelevant to simple behaviors and neurologists could dismiss sensory and motor processing as trivial implementation details with no relevance to cognitive function. It is this pressing and simple fact that we hope this exciting set of articles illustrates.

We, therefore, begin this issue with three articles that cut across the entire breadth of cognitive neuroscience. Garland (a lawyer) and Glimcher (a neurobiologist) open the issue with a commentary: *Cognitive neuroscience and the law*. Most neurobiologists do not realize that cognitive experiments being performed today are exerting influences that not only span the neurosciences but extend well beyond the existing boundaries of our field, influencing legal practice in the United States and other western counties. The authors discuss the current legal mechanisms for incorporating scientific insight into legal practice, and raise serious issues that bear on legal practice today. Our hope is that for our readers this article will both cast current cognitive neuroscience within a larger social framework and caution members of our community to consider the social implications of the experiments they conduct and the words they use to describe those experiments.

In the next article, *From crawling to cognition: analyzing the dynamical interactions among populations of neurons*, we move from the broadest social perspective on human behavior to landmark studies of multi-neuronal interaction in an invertebrate, the medicinal leech. In this article Briggman Abarbanel and Kristan describe a new mathematical technique for identifying functional interactions among large populations of neurons that might have a significant impact on cognitive neuroscience at all levels. Their recent studies have focused on understanding how the leech decides whether to swim or crawl while the activity of literally hundreds of neurons is measured simultaneously. Their novel analytical technique enables them to query how ensembles coordinate to control behavior. What is exciting about this technique is that it could overcome a significant obstacle that has dogged researchers working at all levels of cognitive neuroscience; how to deal with too many results. Even more thrilling is that the approach described in this physiological study of the leech could shape neurological studies of humans in the years to come; a development that is typical of the cognitive neurosciences today.

The article that follows provides this same kind of broad and influential insight from the opposite side of the neurobiological spectrum. In their article on *Generalist genes and cognitive neuroscience*, Butcher, Kennedy and Plomin argue that a single set of genes affects most cognitive abilities and disabilities, and that discovery of these genes will pave the way for a systems-level understanding of how genetically driven brain processes work together to affect diverse cognitive abilities and disabilities. In this article the influences of genetics and psychology meet at the cell biological processes that underlie mental ability.

High-level vision

Having made the point that the cognitive neurosciences respect almost no real disciplinary boundaries, we next turn to examine advances in our understanding of perceptual processing. The challenge we pose to our readers is to see how even these articles challenge the boundaries of the traditional subdiscipline of vision. The authors discuss the ways that the functioning of the visual system can vary, both within an individual, as a function of experience and attention, and across individuals, as a function of natural variations in perceptual abilities across the population.

Until recently, studies of the organization and function of the visual pathway have assumed the adult visual system to be fixed and immutable. Yet behavioral and neural studies from the past two decades have emphasized the ability of perceptual processing systems to adapt to experiential input. In their article on *Learning and neural plasticity in visual object recognition*, Kourtzi and DiCarlo draw on data from neurophysiology and neuroimaging to investigate how experience shapes the machinery of vision at multiple stages along the visual processing pathway.

Moore's article, *The neurobiology of visual attention: finding sources*, explores the ways that the visual function changes from one moment to the next to best serve the goals of the perceiver. This ability, known as attention, is starting to be understood at multiple levels, from the location of the brain regions that direct attention to the functioning of the neural circuits that implement it.

Finally, in their article *Developmental prosopagnosia: a window to content-specific face processing*, Duchaine and Nakayama describe a fascinating phenomenon in which apparently normal individuals with few, if any, other perceptual or cognitive impairments, and no known neurological problems, have severe and lifelong impairments in face recognition. In some cases the deficit is extremely specific, providing powerful evidence for domain-specific perceptual processing mechanisms.

Memory

In *Reconsolidation: the advantage of being refocused*, Dudai reexamines recent controversial work suggesting that when at least some kinds of memory are retrieved, those memories become highly labile. Dudai, a renaissance scholar in our field, argues that the controversy surrounding this work might have more to do with disciplinary boundaries than with the science itself. He argues for a deeper perspective on these findings and a more synthetic approach to these issues.

Next, Moscovitch *et al.* describe new work on the neuroscience of memory at a systems level. Their article, *The cognitive neuroscience of remote episodic, semantic and spatial memory*, challenges established theories of memory consolidation and the role of medial temporal structures in it, and the authors offer their own alternative, multiple trace theory. Although their new theory raises many questions, it is an exciting development in the study of memory that we feel deserves broad and careful scrutiny.

Decision-making

All of the cognitive processes described in the issue up to this point serve as inputs to the decision-making processes that guide behavior. In the past few years astounding progress has been made towards understanding how these decision-making circuits in the primate brain work. Lee begins this section with his article *Neural basis of quasi-rational decision making*. This article reviews the emerging convergence of economic, psychological and neuroscientific studies of decision-making. He also discusses exciting new studies of social decision making, and reviews what all of these studies can tell us about the representation of high-level cognitive processes, such as those described earlier in the issue.

Daw and Doya then go on to describe recent studies of dopamine and decision making in their article *The computational neurobiology of learning and reward*. Very recent studies have begun to explain how neural circuits associated with the neurotransmitter dopamine enable humans and animals to learn the values of their actions by trial and error. These studies of reinforcement learning and decision also draw on a variety of disciplines ranging from machine learning to economics. The conclusions the authors draw from these studies suggest that we already have a surprisingly deep knowledge of how the brain learns from its actions when it comes to decision making.

Action

Decisions influence behavior only in so far as they lead to actions. The next section of this issue examines the neural substrates for action. Culham and Valyear, in their article *Human parietal cortex in action*, describe evidence that distinct regions of the human parietal lobe are engaged in different aspects of visually guided action: reaching, grasping and eye movements. They also discuss the role of these and other parietal regions in processing of action-related information, even when no actual action occurs.

Ashe *et al.* expand on some of these same issues in their article on the *Cortical control of motor sequences*. The generation of behavioral sequences is in many ways a microcosm of cognitive neuroscience, it is a sequence of events within which memory, movement and decision meet. Unsurprisingly then, this article about motor control examines brain areas ranging from the dorsolateral prefrontal to posterior parietal cortices. In a manner typical of cognitive neuroscience, the issues of implicit and explicit learning are raised in the quest to understand motor control.

Cognition

Evidence from multiple methods suggests that primates have early-developing cognitive and neural mechanisms for a small set of key domains of cognition, such as understanding numerical quantity and understanding the intentions and beliefs of conspecifics. In this section we consider recent findings from a few of these domains.

Brannon begins this section with an overview of how numerical magnitude is represented in the minds and brains of a variety of primates in her article, *The representation of numerical magnitude*. She describes recent behavioral experiments from a number of labs examining how young and adult humans, and non-human animals, represent the abstract concept of number. She then goes on to describe exciting neurobiological work on the substrate for numerical cognition.

An explosion of interest in the general area of social cognitive neuroscience has occurred in the past five years. In their article, *Reflections of other minds: how primate social cognition can inform the function of mirror neurons*, Lyons, Santos and Keil consider the implications of mirror neurons, which become activated in monkeys during the performance and the observation of a motor action. They suggest a fascinating new answer to the puzzle of why monkeys can't imitate, given that mirror neurons would seem to be the ideal neural substrate for imitation.

In her article, *Uniquely human social cognition*, Saxe reviews recent findings from neuroimaging that point to five different cortical regions in humans, each implicated in a subtly different aspect of the general task of understanding other people. Perhaps most exciting here is the recent discovery that a distinct region at the temporo-parietal junction is very selectively engaged in reasoning about the contents of another person's beliefs.

Finally, in *Neuroimaging of syntax and syntactic processing*, Grodzinsky and Friederici consider the evidence, largely from neuroimaging, for cortical localization of aspects of syntactic processing. They argue that some distinct components of syntax are housed in distinct cerebral loci and, furthermore, that the cortical regions involved in syntactic processing extend beyond the traditional language regions.

Conclusions

It is an exciting time to be a cognitive neuroscientist. New discoveries are popping up at an unprecedented rate, and connections are being made across traditional disciplinary lines. Real progress is being made on one of the greatest scientific quests of all time: the effort to understand the nature and workings of the human mind.