Introduction to *The Oxford Handbook of Cognitive Neuroscience*: Cognitive Neuroscience—Where Are We Now?

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The Oxford Handbook of Cognitive Neuroscience, Volume 1: Core Topics
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Abstract and Keywords

This two-volume set reviews the current state-of-the art in cognitive neuroscience. The introductory chapter outlines central elements of the cognitive neuroscience approach and provides a brief overview of the eight sections of the book's two volumes. Volume 1 is divided into four sections comprising chapters that examine core processes, ways in which they develop across the lifespan, and ways they may break down in special populations. The first section deals with perception and addresses topics such as the abilities to represent and recognize objects and spatial relations and the use of top-down processes in visual perception. The second section focuses on attention and how it relates to action and visual motor control. The third section, on memory, covers topics such as working memory, semantic memory, and episodic memory. Finally, the fourth section, on language, includes chapters on abilities such as speech perception and production, semantics, the capacity for written language, and the distinction between linguistic competence and performance.

Keywords: cognitive neuroscience, perception, attention, language, memory, spatial relations, visual perception, visual motor control, semantics, linguistic competence

On a night in the late 1970s, something important happened in a New York City taxicab: A new scientific field was named. En route to a dinner at the famed Algonquin Hotel, the neuroscientist Michael Gazzaniga and the cognitive psychologist George Miller coined the term "cognitive neuroscience." This field would go on to change the way we think about the relationship between behavior, mind, and brain.

This is not to say that the field was *born* on that day. Indeed, as Hermann Ebbinghaus (1910) noted, "Psychology has a long past, but a short history," and cognitive neuroscience clearly has a rich and complex set of ancestors. Although it is difficult to say exactly when a new scientific discipline came into being, the groundwork for the field had begun to be laid decades before the term was coined. As has been chronicled in detail elsewhere (Gardner, 1985; Posner & DiGirolamo, 2000), as behaviorism gave way to the cognitive revolution, and as computational and neuroscientific approaches to understanding the mind became increasingly popular, researchers in numerous allied fields came to believe that understanding the relationships between behavior and the mind required understanding their relationship to the brain.

This two-volume set reviews the current state-of-the art in cognitive neuroscience, some 35 years after the field was named. In these intervening years, the field has grown tremendously—so much so, in fact, that cognitive neuroscience is now less a bounded discipline focused on specific topics and more an approach that permeates psychological and neuroscientific inquiry. As such, no collection of chapters could possibly encompass the entire breadth and depth of cognitive neuroscience. That said, this two-volume set attempts systematically to survey eight core areas of inquiry in cognitive neuroscience, four per volume, in a total of 55 chapters.

(p. 2) As an appetizer to this scientific feast, this introductory chapter offers a quick sketch of some central elements of the cognitive neuroscience approach and a brief overview of the eight sections of the *Handbook's* two volumes.

The Cognitive Neuroscience Approach

Among the many factors that gave rise to cognitive neuroscience, we highlight three signal insights. In part, we explicitly highlight these key ideas because they lay bare elements of the cognitive neuroscience approach that have become so commonplace today that their importance may be forgotten even as they implicitly influence the ways research is conducted.

Multiple Levels of Analysis

The first crucial influence on cognitive neuroscience were insights presented in a book by the late British vision scientist David Marr. Published in 1982, the book *Vision* took an old idea—levels of analysis—and made a strong case that we can only understand visual perception if we integrate descriptions cast at three distinct, but fundamentally interrelated (Kosslyn & Maljkovic, 1990), levels. At the topmost *computational* level, one describes the problem at hand, such as how one can see edges, derive three-dimensional structure of shapes, and so on; this level characterizes “what” the system does. At the middle *algorithm* level, one describes how a specific computational problem is solved by a system that includes specific processes that operate on specific representations; this level characterizes “how” the system operates. And at the lowest *implementation* level, one describes how the representations and processes that constitute the algorithm are instantiated in the brain. All three levels are crucial, and characteristics of the description at each level affect the way we must describe characteristics at the other levels.

This approach proved enormously influential in vision research, and researchers in other domains quickly realized that it could be applied more broadly. This multilevel approach is now the foundation for cognitive neuroscience inquiry more generally, although we often use different terminology to refer to these levels of analysis. For instance, many researchers now talk about the levels of behavior and experience, psychological processes (or information processing mechanisms), and neural systems (Mitchell, 2006; Ochsner, 2007; Ochsner & Lieberman, 2001). But the core idea is still the same as that articulated by Marr: A complete understanding of the ways in which vision, memory, emotion, or any other cognitive or emotional faculty operates necessarily involves connecting descriptions of phenomena across levels of analysis.

The resulting multilevel descriptions have many advantages over the one- or two-level accounts that are typical of traditional approaches in allied disciplines such as cognitive psychology. These advantages include the ability to use both behavioral and brain data in combination—rather than just one or the other taken alone—to draw inferences about psychological processes. In so doing, one constructs theories that are constrained by, must connect to, and must make sense in the context of more types of data than theories that are couched solely at the behavioral or at the behavioral and psychological levels. We return to some of these advantages below.

Use of Multiple Methods

If we are to study human abilities and capacities at multiple levels of analysis, we must necessarily use multiple types of methods to do so. In fact, many methods exist to measure phenomena at each of the levels of analysis, and new measures are continually being invented (Churchland & Sejnowski 1988).

Today, this observation is taken as a given by many graduate students who study cognitive neuroscience. They take it for granted that we should use studies of patient populations, electrophysiological methods, functional imaging methods, transcranial magnetic stimulation (TMS, which uses magnetic fields to temporarily impair or enhance neural functioning in a specific brain area), and other new techniques as they are developed. But this view wasn't always the norm. This fact is illustrated nicely by a debate that took place in the early 1990s about whether and how neuroscience data should inform psychological models of cognitive processes. On one side was the view from *cognitive neuropsychology,* which centered on the idea that studies of patient populations may be sufficient to understand the structure of cognitive processing (Caramazza, 1992). The claim was that by studying the ways in which behavior changes as a result of the unhappy accidents of nature (e.g., strokes, traumatic brain injuries) that caused lesions of language areas, memory areas, and so on, we can discover the processing modules that constitute the mind. The key assumption here is that researchers can identify direct relationships between behavioral deficits and specific areas of the brain that were damaged. On the other side of the debate was the view from *cognitive neuroscience,* (p. 3) which centered on the idea that the more methods used, the better (Kosslyn & Intriligator, 1992). Because every method has its limitations, the more methods researchers could bring to bear, the more likely they are to have a correct picture of how behavior is related to neural functioning. In the case of patient populations, for example, in some cases the deficits in behavior might not simply reflect the normal functions of the damaged regions; rather, they could reflect reorganization of function after brain damage or diffuse damage to multiple regions that affects multiple separate functions. If so, then observing patterns of dissociations and associations of abilities following brain damage would not necessarily allow researchers to delineate the structure of cognitive processing. Other methods would be required (such as neuroimaging) to complement studies of brain-damaged patients.

The field quickly adopted the second perspective, drawing on multiple methods when constructing and testing theories of cognitive processing. Researchers realized that they could use multiple methods together in complementary ways: They could use functional imaging methods to describe the network of processes active in the healthy brain when engaged in a particular behavior; they could use lesion methods or TMS to assess the causal relationships between activity in specific brain areas and particular forms of information processing (which in turn give rise to particular types of behavior); they could use electrophysiological methods to study the temporal dynamics of cortical systems as they interactively relate to the behavior of interest. And so on. The cognitive neuroscience approach adopted the idea that no single technique provides all the answers.

That said, there is no denying that some techniques have proved more powerful and generative than others during the past 35 years. In particular, it is difficult to overstate the impact of functional imaging of the healthy intact human brain, first ushered in by positron emission tomography studies in the late 1980s (Petersen et al., 1988) and given a tremendous boost by the advent of, and subsequent boom of, functional magnetic resonance imaging in the early 1990s (Belliveau et al., 1992). The advent of functional imaging is in many ways the single most important contributor to the rise of cognitive neuroscience. Without the ability to study cortical and subcortical brain systems in action in healthy adults, it's not clear whether cognitive neuroscience would have become the central paradigm that it is today.

We must, however, offer a cautionary note: Functional imaging is by no means the be-all and end-all of cognitive neuroscience techniques. Like any other method, it has its own strengths and weaknesses (which have been described in detail elsewhere, e.g., Poldrack, 2006, 2008, 2011; Van Horn & Poldrack, 2009; Yarkoni et al., 2010). Researchers trained in cognitive neuroscience understand many, if not all, of these limitations, but unfortunately, many outside the field do not. This can cause two problems. The first is that newcomers to the field may improperly use functional imaging in the service of overly simplistic "brain mapping" (e.g., seeking to identify "love spots" in the brain; Fisher et al., 2002) and may commit other inferential errors (Poldrack, 2006). The second, less appreciated problem, is that when nonspecialists read about studies of such overly simplistic hypotheses, they may assume that all cognitive neuroscientists traffic in this kind of experimentation and theorizing. As the chapters in these volumes make clear, most cognitive neuroscientists appreciate the strengths and limits of the various techniques they use, and understand that functional imaging is simply one of a number of techniques that allow neuroscience data to *constrain* theories of psychological processes. In the next section, we turn to exactly this point.

Constraints and Convergence

One implication of using multiple methods to study phenomena at multiple levels of analysis is that we have numerous types of data. These data provide converging evidence for, and constrain the nature of, theories of human cognition, emotion, and behavior. That is, the data must fit together, painting different facets of the same picture (this is what we mean by convergence). And even though each type of data alone does not dictate a particular interpretation, each type helps to narrow the range of possible interpretations (this is what we mean by constraining the nature of theories). Researchers in cognitive neuroscience acknowledge that data always can be interpreted in various ways, but they also rely on the fact that data limit the range of viable interpretations—and the more types of data, the more strongly they will narrow down the range of possible theories. In this sense, constraints and convergence are the very core of the cognitive neuroscience approach (Ochsner & Kosslyn, 1999).

We note that the principled use of constraining and converging evidence does not privilege evidence couched at any one level of analysis. Brain data are not more important, more real, or more (p. 4) intrinsically valuable than behavioral data, and vice versa. Rather, both kinds of data constrain the range of possible theories of psychological processes, and as such, both are valuable.

In addition, both behavioral and brain data can spark changes in theories of psychological processes. This claim stands in contrast to claims made by those who have argued that brain data can never change, or in any way constrain, a psychological theory. According to this view, brain data are ambiguous without a psychological theory to interpret them (Kihlstrom, 2012). Such arguments fail to appreciate the fact that the goal of cognitive neuroscience is to construct theories couched at all three levels of analysis. Moreover, behavioral and brain data often are dependent variables collected in the same experiments. This is not arbitrary; we have ample evidence that behavior and brain function are intimately related: When the brain is damaged in a particular location, specific behaviors are disrupted—and when a person engages in specific behaviors, specific brain areas are activated. Dependent measures are always what science uses to constrain theorizing, and thus it follows that *both* behavioral and brain data *must* constrain our theories of the intervening psychological processes.

This point is so important that we want to illustrate it with a two examples. The first begins with classic studies of the amnesic patient known for decades only by his initials, H.M. (Corkin, 2002). After he died, his brain was famously donated to science and dissected live on the Internet in 2009 (see http://thebrainobservatory.ucsd.edu/hm_live.php). We now know that his name was Henry. In the 1960s, Henry suffered from severe epilepsy that could not be treated with medication, which arose because of abnormal neural tissue in his temporal lobes. At the time, he suffered horribly from seizures, and the last remaining course of potential treatment was a neurosurgical operation that removed the tips of Henry's temporal lobes (and with them, the neural origins of his epileptic seizures).

When Henry awoke after his operation, the epilepsy was gone, but so was his ability to form new memories of events he experienced. Henry was stuck in the eternal present, forevermore awakening each day with his sense of time frozen at the age at which he had the operation. The time horizon for his experience was about two minutes, or the amount of time information could be retained in short-term memory before it required transfer to a longer-term episodic memory store.

To say that the behavioral sequelae of H.M.'s operation were surprising to the scientific community at that time is an understatement. Many psychologists and neuroscientists spent the better part of the next 20 to 30 years reconfiguring their theories of memory in order to accommodate these and subsequent findings. It wasn't until the early 1990s that the long-reaching theoretical implications of Henry's amnesia finally became clear (Schacter & Tulving, 1994), when a combination of behavioral, functional imaging, and patient lesion data converged to implicate a multiple-systems account of human memory.

This understanding of H.M.'s deficits was hard won, and emerged only after an extended "memory systems debate" in psychology and neuroscience (Schacter & Tulving, 1994). This debate was between, on the one hand, behavioral and psychological theorists who argued that we have a single memory system (which has multiple processes) and, on the other hand, neuroscience-inspired theorists who argued that we have multiple memory systems (each of which instantiates a particular kind of process or processes). The initial observation of H.M.'s amnesia, combined with decades of subsequent careful experimentation using multiple behavioral and neuroscience techniques, decisively came down on the side of the multiple memory systems theorists. Cognitive processing relies on multiple types of memory, and each uses a distinct set of representations and processes. This was a clear victory for the cognitive neuroscience approach over purely behavioral approaches.

A second example of the utility of combining neuroscientific and behavioral evidence comes from the "imagery debate" (Kosslyn, Thompson, & Ganis, 2006). On one hand, some psychologists and philosophers argued that the pictorial characteristics of visual mental images that are evident to experience are epiphenomenal, like heat produced by a light bulb when someone is reading—something that could be experienced but played no role in accomplishing the function. On the other hand, cognitive neuroscientists argued that visual mental images are analogous to visual percepts in that they use space in a representation to specify space in the world.

This debate went back and forth for many years without resolution, and at one point a mathematical proof was offered that behavioral data alone could never resolve it (Anderson, 1978). The advent of neuroimaging helped bring this debate largely to a close (Kosslyn, Thompson, & Ganis, 2006). A key (p. 5) finding was that the first cortical areas that process visual input during perception each are topographically mapped, such that adjacent locations in the visual world are represented in adjacent locations in the visual cortex. That is, these areas use space on the cortex to represent space in the world. In the early 1990s, researchers showed that visualizing objects typically activates these areas, and increasing the size of a visual mental image activates portions of this cortex that register increasingly larger sizes in perception. Moreover, in the late 1990s researchers showed that temporarily impairing these areas using TMS hampers imagery and perception to the same degree. Hence, these brain-based findings provided clear evidence that visual mental images are, indeed, analogous to visual percepts in that both represent space in the world by using space in a representation.

We have written as if both debates—about memory systems and mental imagery representation—are now definitely closed. But this is a simplification; not everyone is convinced of one or another view. Our crucial point is that the advent of neuroscientific data has shifted the terms of the debate. When only behavioral data were available, in both cases the two alternative positions seemed equally plausible—but after the relevant neuroscientific data were introduced, the burden of proof shifted dramatically to one side—and a clear consensus emerged in the field (e.g., see Reisberg, Pearson, & Kosslyn, 2003).

In the years since these debates, evidence from cognitive neuroscience has constrained theories of a wide range of phenomena. Many such examples are chronicled in this *Handbook*.

Overview of the *Handbook*

Cognitive neuroscience in the new millennium is a broad and diverse field, defined by a multileveled integrative approach. To provide a systematic overview of this field, we've divided this *Handbook* into two volumes.

Volume 1

The first volume surveys classic areas of interest in cognitive neuroscience: perception, attention, memory, and language. Twenty years ago when Kevin Ochsner was a graduate student and Stephen Kosslyn was one of his professors, research on these topics formed the backbone of cognitive neuroscience research. And this is still true today, for two reasons.

First, when cognitive neuroscience took off, these were the areas of research within psychology that had the most highly developed behavioral, psychological, and neuropsychological (i.e., brain-damaged patient based) models in place. And in the case of research on perception, attention, and memory, these were topics for which fairly detailed models of the underlying neural circuitry already had been developed on the basis of rodent and nonhuman primate studies. As such, these areas were poised to benefit from the use of brain-based techniques in humans.

Second, research on the representations and processes used in perception, attention, memory, and language in many ways forms a foundation for studying other kinds of complex behaviors, which are the focus of the second volume. This is true both in terms of the findings themselves and in terms of the evidence such findings provided that the cognitive neuroscience approach could be successful.

With this in mind, each of the four sections in *Volume 1* includes a selection of chapters that cover core processes and the ways in which they develop across the lifespan and may break down in special populations.

The first section, on perception, includes chapters on the abilities to represent and recognize objects and spatial relations. In addition, this section contains chapters on the use of top-down processes in visual perception and on the ways in which such processes enable us to construct and use mental images. We also include chapters on perceptual abilities that have seen tremendous research growth in the past 5 to 10 years, such as on the study of olfaction, audition, and music perception. Finally, there is a chapter on disorders of perception.

The second section, on attention, includes chapters on the abilities to attend to auditory and spatial information as well as on the relationships between attention, action, and visual motor control. These are followed by chapters on the development of attention and its breakdown in various disorders.

The third section, on memory, includes chapters on the abilities to maintain information in working memory as well as semantic memory, episodic memory, and the consolidation process that governs the transfer of information from working to semantic and episodic memory. There is also a chapter on the ability to acquire skills, which depends on different systems than those used in other forms of memory, as well as chapters on changes in memory function with older age and the ways in which memorial processes break down in various disorders.

Finally, the fourth section, on language, includes chapters on abilities such as speech perception and production, the distinction between linguistic (p. 6) competence and performance, semantics, the capacity for written language, and multimodal and developmental aspects of speech perception.

Volume 2

Whereas *Volume 1* addresses the classics of cognitive neuroscience, *Volume 2* focuses on the "new wave" of research that has developed primarily in the past 10 years. As noted earlier, in many ways the success of these relatively newer research directions builds on the successes of research in the classic domains. Indeed, our knowledge of the systems implicated in perception, attention, memory, and language literally—and in this *Handbook*—provided the foundation for the work described in *Volume 2*.

The first section, on emotion, begins with processes involved in interactions between emotion, perception, and attention, as well as the generation and regulation of emotion. This is followed by chapters that provide models for understanding broadly how emotion affects cognition as well as the contribution that bodily sensation and control make to affective and other processes. This section concludes with chapters on genetic and developmental approaches to emotion.

The second section, on self and social cognition, begins with a chapter on the processes that give rise to the fundamental ability to know and understand oneself. This is followed by chapters on increasingly complex abilities involved in perceiving others, starting with the perception of nonverbal cues and perception–action links, and from there ranging to face recognition, impression formation, drawing inferences about others' mental states, empathy, and social interaction. This section concludes with a chapter on the development of social cognitive abilities.

The third section, on higher cognitive functions, surveys abilities that largely depend on processes in the frontal lobes of the brain, which interact with the kinds of core perceptual, attentional, and memorial processes described in *Volume 1*. Here, we include chapters on conflict monitoring and cognitive control, the hierarchical control of action, thinking, decision making, categorization, expectancies, numerical cognition, and neuromodulatory influences on higher cognitive abilities.

Finally, in the fourth section, four chapters illustrate how disruptions of the mechanisms of cognition and emotion produce abnormal functioning in clinical populations. This section begins with a chapter on attention deficit-hyperactivity disorder and from there moves to chapters on anxiety, post-traumatic stress disorder, and obsessive-compulsive disorder.

Summary

Before moving from the appetizer to the main course, we offer two last thoughts.

First, we edited this *Handbook* with the goal of providing a broad-reaching compendium of research on cognitive neuroscience that will be widely accessible to a broad audience. Toward this end, the chapters included in this *Handbook* are available online to be downloaded individually. This is the first time that chapters of a *Handbook* of this sort have been made available in this way, and we hope this facilitates access to and dissemination of some of cognitive neuroscience's greatest hits.

Second, we hope that, whether you are a student, an advanced researcher, or an interested layperson, this *Handbook* whets your appetite for learning more about this exciting and growing field. Although reading survey chapters of the sort provided here is an excellent way to become oriented in the field and to start building your knowledge of the topics that interest you most, we encourage you to take your interests to the next level: Delve into the primary research articles cited in these chapters—and perhaps even get involved in doing this sort of research!

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