

89 The Landscape of Cognitive Neuroscience: Challenges, Rewards, and New Perspectives

1

ELISSA M. AMINOFF, DANIELA BALSLEV, PAOLA BORRONI, RONALD E. BRYAN,
ELIZABETH F. CHUA, JASMIN CLOUTIER, EMILY S. CROSS, TRAFTON DREW, CHADD M. FUNK,
RICARDO GIL-DA-COSTA, SCOTT A. GUERIN, JULIE L. HALL, KERRY E. JORDAN,
AYELET N. LANDAU, ISTVAN MOLNAR-SZAKACS, LEILA MONTASER-KOUHSARI,
JONAS K. OLOFSSON, SUSANNE QUADFLIEG, LEAH H. SOMERVILLE, JOCELYN L. SY,
LUCINA Q. UDDIN, AND MAKIKO YAMADA

The chapters in the volume you are holding reflect an ever-evolving understanding of how the brain—from genes to proteins, from cells to systems, and building blocks in between—generates behavior. Before publication of this book, 22 fellows of the Summer Institute in Cognitive Neuroscience attended a three-week meeting centered on the topics within this text and were challenged by Michael Gazzaniga to write a commentary reflecting current issues in the field. It is not an easy task to integrate a variety of conceptual and methodological approaches and produce an insightful commentary while escaping oversimplification of the issues. Nonetheless, the enterprise proved both exciting and worthwhile, and we hope that it illuminates and unifies some seemingly disparate concepts in a new light. Consistent with the nature of the cognitive neurosciences, we are a heterogeneous, multidisciplinary group. It is from this perspective, by tying together themes that transcend traditional research topics, that we present here our own reflections as we look toward the future of the field.

First, we will discuss recent methodological developments that have allowed for greater integration across multiple levels of analysis. These methods have expanded the range of research questions that can be asked and in some cases have led to new theoretical approaches. In turn, novel theoretical models have generated profound shifts in research foci. Cognitive neuroscientists are now exploring topics that were previously considered impossible or implausible for

scientific investigation (e.g., social cognitive neuroscience) and are also revisiting old themes with a new mindset (e.g., the contribution of nature versus nurture). To conclude, we reflect on how this “new” cognitive neuroscience is beginning to influence everyday life, including public policy, education, and healthcare.

Methods

The evolution of cognitive neuroscience has been driven largely by the development of increasingly sophisticated experimental methods. These methods and novel techniques enable us to address hypotheses that were previously unimaginable, such as establishing a causal relationship between patterns of neural activity, cognitive processes, and complex behavior. Methods that are currently under development are allowing us to better estimate the spatiotemporal structure of neural data, move from correlation-based methods to experimental manipulation of brain activity, and gain a deeper understanding of the importance and instructive value of individual differences.

One significant outcome of recent technological advances is the ability to quantitatively measure brain structure (e.g., diffusion tensor imaging and virus tracing technology) and function (e.g., high-resolution functional magnetic resonance imaging (fMRI) and single-unit recordings in humans) at a higher spatial and/or temporal resolution than ever before. The enhanced precision of these measurements is accompanied by increasingly sophisticated data analysis techniques, computational models, and theoretical interpretations. For example, novel multivariate and pattern classification approaches to fMRI data have revealed a spatial structure of hemodynamic activity beyond what is evident from

traditional univariate approaches (Carlson, Schrater, & He, 2003; Cox & Savoy, 2003).

One challenge that remains is to bring these methods to bear on the long-standing issue of modular versus distributed processing networks in the brain. An increasing number of multivariate analysis techniques enable us to describe brain activity on a network level, including independent and principal component analyses, dynamic causal modeling, and multivoxel pattern analysis. Such methods allow us to test existing theoretical ideas but also reveal new issues that were previously not accessible to scientific measurement. For example, pattern classification techniques have reframed the issue of object processing in the ventral temporal cortex from *where* an object is represented to *how* patterns of brain activity represent information (Norman, Polyn, Detre, Haxby, 2006). We anticipate further methodological advances, as increased resolution reveals new scales of organization of the human brain.

A key objective of any scientific investigation is to uncover causal structure. Continuing advances in functional brain imaging enable neuroscientists to infer functional-anatomical correlates from patterns of blood flow during task performance, but these methods are limited to uncovering correlational links, not causal ones. Historically, the ability to draw conclusions regarding the necessity of a brain structure to perform a particular cognitive operation has been limited to lesion studies in animals and the rare occurrence of focal lesions in humans due to brain insults or surgery. In recent years, new methodological techniques such as transcranial magnetic stimulation (TMS) have enabled the noninvasive manipulation of cortical activity in healthy individuals (Chapter 9 in this volume). Additionally, in neurosurgical settings, researchers are increasingly using electrical microstimulation to directly activate a particular population of neurons and study its behavioral outcomes, as well as changes in the neurophysiology locally (around the electrode) and in other other parts of the brain that are connected to the stimulated region, (e.g., Kawasaki & Sheinberg, 2008; Houweling & Brecht, 2008). On a different scale, gene knockout manipulations in mice reveal remarkable insights into the genetic basis of cognition and behavior (e.g., Hung et al., 2008; Gunnerson et al., 2007). For example, Hung and colleagues have found enhanced performance in spatial learning but impaired long-term retention in Shank1 knockout mice, suggesting an important and complex role for the Shank family of proteins in normal cognitive development. Another approach using neuropharmacological methods has led to exciting new data that point to a link between serotonin levels in the brain and interpersonal trust among human participants (Crockett, Clark, Tabibnia, Lieberman, & Robbins, 2008). As we continue to work toward the refinement of this diverse toolbox of experimen-

tal approaches, we are hopeful that they will help to further elucidate the causal links between brain function, structure, and behavior.

An emerging trend in cognitive neuroscience methodology is the study of how individual differences contribute to our understanding of the human brain. Psychologists and neuroscientists have conventionally relied on aggregating data across a sample of subjects to draw conclusions about how the “average” or prototypical brain might function. In reality, individual differences abound in the dynamic interplay between environment, genes, behavior, anatomy, and topographic patterns of brain activity. These differences offer a vast and scarcely explored source of clues about the nature of the mind and brain. To this end, new methods in correlating environmental and genetic variation with neural data offer exciting new possibilities in understanding how genes and the environment interact to produce a unique brain (see Chapters 2, 50, and 64 in this volume). Accounting for interindividual variance not only may give us a more ecologically valid way of looking at cognition, but also may provide important insights into more general, overarching processes that underlie different types of cognition across individuals and perhaps even species. Perplexing as it might seem, understanding universal neural architecture that creates the human condition could rely on first recognizing the complex processes that make each of us unique. 2

Theory

As reflected in the evolution of the topics addressed in *The Cognitive Neurosciences* volumes that have been published over the past 20 years, there have been major advances in how we conceptualize mind, brain, and body interactions. New methods described above have also led to groundbreaking findings related to genetics and synaptic physiology and to the functions and connectivity underlying complex neural networks. One way to better understand the complexity of the brain has been to further integrate levels of analyses, research perspectives, and conceptual approaches.

For example, genes and experience are no longer considered to be polar opposite factors of influence but are instead viewed as dynamically interacting. The emergent view is that genes serve as scaffolding for the ways in which experience can change brain organization and subsequent behavior. Our innate genetic blueprint determines the development of the human brain continuously throughout the life span at various neural levels (e.g., directing cellular organization, pruning, myelination, molecular structures, cortical maturation, and connectivity), laying the biological foundation for behavioral functionality. For example, various genes have been implicated in anomalous maturation of neural systems and developmental disorders (e.g., FOXP2, among other genes in developmental dyslexia) (Ramus, 2006) and have

been linked to the presence of specific psychiatric conditions (e.g., abnormal pruning in schizophrenia and autism) (McGlashan & Hoffman, 2000; Boylan, Blue, & Hohmann, 2007). As our knowledge of gene-environment interactions advances, it becomes ever more evident that while specific genotypes are associated with the phenotypic expression of certain behaviors, environmental factors are also required for the expression of particular genotypes.

An increasingly sophisticated understanding of these gene-environment interactions is one realm in which the concept of dynamic interplays has borne fruitful insights. One can also observe this dynamic interplay at the level of the brain, which is an ever-changing functional system regulated by adaptive feedback mechanisms. Recent experiments have explored the boundaries of this functional flexibility by looking at primary sensory areas, for which the functional architecture was previously thought to be hard-wired. Specifically, Sur and colleagues have shown that if visual input in the ferret is experimentally rewired during development to auditory cortex, there is an emergence of orientation tuning columns in those auditory areas (Majewska & Sur, 2006), an elegant demonstration that the experiential input to primary sensory areas can dramatically alter functional organization.

However, although the input to a brain area has a powerful ability to remodel cortical structure and function, it must act in concert with the scaffolding laid down by genes. Thus while the rewired auditory cortex shares a similar structure with V1, its orientation map was found not to be as regular and precise, showing that while the brain has the capacity for remarkable plasticity, future research will have to delineate the boundaries of this adaptive function.

At a higher level of cognitive operations, adaptive feedback mechanisms have profound influences on brain-behavior relations. This flexibility is essential to keep up with our ever-changing social environments through the adaptive implementation of appropriate behavioral responses. Accordingly, current research emphasizes the role of top-down control over the selection of information relevant to our behavioral goals. These top-down factors are now believed to modulate cognitive processes at many levels. The influence of top-down control can be illustrated by the activity of sensory neurons, which are modulated by task goals. For example, the neural response of early visual cortices

- 3 has been shown to be upregulated prior to the onset of attentional cues (Hopfinger, Buonocore, & Mangun 2000; Giesbrecht et al., 2003). Top-down modulation has also been shown to prepare sensory areas for upcoming stimuli by filtering out, or suppressing, the processing of unnecessary information and enhancing the processing of relevant features as far downstream as the lateral geniculate nucleus within the visual system (O'Connor, Fukui, Pinsk, & Kastner, 2002). This act of filtering information not only has impor-

tant implications in the sensory processing of a stimulus, but also can have a strong impact on how we remember a past event. For example, if an emotional event is depicted within a broader spatial context, our attention is focused on the emotional content, leading recognition memory for the background information to suffer (Kensinger, Piguet, Krendl, & Corkin, 2005).

Top-down and attentional influences have been shown to affect not only systemwide neural activity, but also the precise timing of neural firing patterns within local populations of neurons. For example, increased attention enhances local gamma band synchrony or temporally coincident firing within a population of neurons in the motor system, which, in turn, upregulates the signal output from that region, thereby increasing the speed of behavioral responding (Fries, Womelsdorf, Oostenveld, & Desimone, 2008). These findings demonstrating the flexibility of brain and behavior relationships are a product of integrating different levels of analysis, from genetic expression to neurophysiology to functional organization to manifestations in behavior.

Given the recent trend toward integration of various levels of analysis, there is an emergent move to study neural activity in networks—both local and global—as well as systems across the whole brain. Let's consider an example: Brain regions involved in processing different features of an object (e.g., color, shape, motion trajectories) are reactivated when retrieving visual detail about the object from memory (Martin, 2007). This demonstrates that information about objects is represented via a distributed network in the brain, and various processes related to using such information rely on this distributed network. To fully account for such effects, cognitive processes and their underlying neuronal mechanisms must be analyzed on a global scale. Specifically, traditional neuroimaging studies have focused on the “subtraction paradigm,” in which functional localization is inferred from the brain's response to a particular cognitive task. A shift from localization to understanding large-scale network interactions parallels the emergence of the idea that one can achieve a greater understanding of neural processes by examining dynamic interactions between brain regions. Increasing interest in this network approach is reflected in the growing popularity of integrating multiple neuroimaging techniques in order to understand the structural and spatial (fMRI and diffusion tensor imaging), functional (fMRI, TMS, lesion, and event-related potential (ERP)), and temporal (electroencephalography and ERP) aspects of neural processes.

Another new approach is to study large-scale networks by examining spontaneous, task-independent fluctuations in blood oxygen level dependent (BOLD) signal that can reveal the intrinsic functional architecture of the brain. The first studies by Raichle and colleagues (2001) using positron emission tomography and later fMRI highlighted the fact that

spontaneous neuronal activity accounts for the majority of the brain's energy metabolism. In the last several years, the number of studies using the recently developed method of resting-state functional connectivity, which examines temporal correlations between discrete brain regions, has increased exponentially. While the exact nature and function of so-called resting-state networks and their relationship with anatomical connectivity remain to be elucidated, the field has already progressed to the point at which it is clear that resting-state functional connectivity measures show meaningful correlations with behavioral measures and can be used to understand aberrant cortical connectivity in different clinical populations (Castellanos et al., 2008). Furthermore, this focus on the resting state not only enables analysis of multiple neural networks, but also could have important implications cutting across various fields of cognition. Thus we see the recent emphasis on examination of spontaneous brain activity as an important theoretical advancement with the potential to open new avenues of research in the years to come.

Integration of different levels of analyses has also borne fruit in the fledgling field of social cognitive and affective neuroscience. These efforts have been in part facilitated by the convergence of perspectives (e.g., neuroscience, social psychology, economics, ethology) towards understanding higher-order functions of the human mind. As humans, we constantly reflect on ourselves and regulate our behaviors, thoughts, and emotions. Building on work in many areas of neuroscience (e.g., the study of the neural circuitry associated with various emotional experiences), advances have been made in identifying the role of brain areas involved with self-reflection and self-regulation, broadly defined. For example, recent work has started to reveal networks of brain areas that are recruited when we reflect about ourselves in the past, the present, and the future (Arzy, Molnar-Szakacs, Blanke, 2008; Schacter, Addis, & Buckner, 2007). Another essential aspect of the human mind is our ability to navigate our rich and complex social environment. Indeed, networks of brains areas (i.e., medial prefrontal cortex, superior temporal sulcus, temporoparietal junction, fusiform, intraparietal sulcus, and amygdala) are now believed to be involved in the perception and understanding of others (i.e., their faces, actions, intention, and mental states) (Gobbini & Haxby, 2007; Mitchell, 2008). One conceptual breakthrough has been the idea that we use overlapping neural systems in representing our own knowledge, beliefs, intentions, and actions as we use to understand others. This "simulation" account finds empirical support in work by Rizzolatti and colleagues, who have shown that a special class of neurons located in frontal and parietal cortices in the macaque (e.g., "mirror neurons") respond to both executed and observed actions (Rizzolatti & Craighero 2004). Studies using neuroimaging techniques in humans

have revealed a parallel frontoparietal mirror system that has been implicated in a variety of high-level cognitive and socioemotional processes that may rely, at least in part, on a simulation mechanism, including imitation and intention understanding (Iacoboni et al., 2005). These social cognitive and affective neuroscience approaches are already moving the field in the direction of bringing more ecological validity to the study of cognitive neuroscience, paralleling the social world in which we live.

Integrating cognitive neuroscience

The common underlying question shared by the many lines of research collected in the chapters of this book can perhaps be summarized as "How does the human brain integrate multiple levels of neural responses—from molecules to neurons, to circuits—to produce adaptive behavior?" Immediately, a second-order question comes to mind: "How do *we* make sense of all the information that we have acquired about these systems in the past 100 years?" While reading the previous sections on the current theoretical and methodological advances in the field, three key themes seem to stand out with striking relevance: *time*, *context* and *integration*.

Although none of the themes is new per se, they reemerge in current research and shape the landscape of the field in new ways. The necessity for an integrated approach to the space-time dimensions has always been a fundamental framework in the study of cognitive neurosciences. Recently, in addition to the quest for localization of function, an increased emphasis is placed on describing the temporal unfolding of neural activity, such as elucidating neural networks sharing temporal synchrony.

As such, *time* can be seen as a defining element of change, a critical feature to both brain physiology and behavioral output. For example, change in molecular constitution and neural connectivity determines the acquisition of new functional properties during development, perception, learning, memory encoding and retrieval, attention, and every other cognitive activity that one might consider. From an ontogenetic perspective, the temporal unfolding of plasticity critically shapes the growing organism's cognitive machinery, from cellular mechanisms such as specialized neuronal growth and wiring to later developmental stages associated with higher cognitive functions such as language (Chapter 4 in this volume).

In a phylogenetic perspective, the timescale expands to include the historical record of progress toward understanding the biological bases of cognition. Thus the importance of the study of multiple biological models, with last common ancestors at different evolutionary times, has become increasingly recognized (for coverage of this topic, see Platek, Keenan, & Shackleford, 2006).

The consideration of *context* in current research emerges as an increasingly exciting dimension in cognitive neuroscience. It is now evident that the substrates of cognitive functions cannot be studied in isolation but that insight into their mechanisms and consequent outcomes can be gained only from the full contextual setting in which they develop and operate. From neuronal activity being strongly modulated by the extracellular surround and glial support to the environmental context influencing the processing of a given stimulus, context plays a critical role in driving and explaining neural activity. One can also consider context more broadly, such as the evolutionary forces that have shaped human and nonhuman primate brains and behavior, driven by ecological and environmental factors. From cellular to systems to social neurosciences, there is no scarcity of examples demonstrating the importance of context.

Finally, the pages of this book consistently remind us of the overwhelming importance of integration. We believe that now is an excellent time for integration at all levels! Critical to the advancement of the field is integration in many forms: of methods, of biological models, and of conceptual perspectives, all reflected in the integration of researchers with very different scientific backgrounds investigating the complexity of the multifaceted discipline of cognitive neuroscience.

Clearly, the advancement of cognitive neuroscience strongly relies on the integration of knowledge across perspectives and domains. The attempt to overcome these limits is already evident in the current use of multiple techniques and interdisciplinary approaches, as well as in the increasing number of multidisciplinary teams and research collaborations. An integrative approach is fundamental to the achievement of our common goal: understanding the multitude of complex neural systems at the core of the causal relationship between our brain and our behavior.

Cognitive neuroscience and society

Over the past two decades, the field of cognitive neuroscience has developed at a frenetic pace. A new wave of research has moved past basic work aimed at understanding brain function toward examining the neural underpinnings of issues that are critically important to humanity. This is admittedly a lofty goal, but cognitive neuroscience has already made important contributions across several spheres of society. In conclusion, we highlight two specific cases in which the study of the brain clarifies and enhances our understanding and social well-being: uncovering the etiology and treatment mechanisms of psychiatric illness and informing behavioral interventions to enhance classroom learning for at-risk young children. While illuminating some societal issues, applied cognitive neuroscience research has complicated others, such as giving rise to legal controversies by

fueling debates within the criminal justice system regarding culpability for our actions given certain brain insults. Finally, the surge in applied work has also placed neuroscience research squarely in the public eye. We will conclude with a discussion of the heightened responsibility required of scientists to communicate their findings to the general public in an informative and accurate fashion.

Cognitive neuroscience research is making important contributions in a number of clinical domains, notably in our understanding of the etiology of psychiatric disorders such as depression. For example, brain research has led to the development of animal models that provide a unique window into the cellular and molecular mechanisms of this disorder (Fuchs & Flugge, 2006; McArthur & Borsini, 2006). In humans, neuroimaging techniques in combination with genetic analyses have assisted in characterizing both the structural and functional profiles associated with affective disorders. For instance, the serotonin transporter gene linked polymorphic region (5-HTTLPR) has been identified as a predictor of vulnerability for affective disorders and exaggerated amygdala response to emotional stimuli, as observed by using fMRI techniques (Munafo, Brown, & Hariri, 2008). Patterns of fMRI activity can also predict the probability of remission from clinical depression and potentially guide treatment choices. Canli and colleagues (2005) found that greater amygdala activation to emotional faces predicts subsequent symptom reduction in depressed patients, identifying a subgroup of individuals who are predicted to have poorer chances of spontaneous alleviation of depressed symptoms. Furthermore, a number of experiments suggest that repetitive TMS to certain cortical regions might actually exert clinically significant antidepressant effects. Several studies from the laboratory of Alvaro Pascual-Leone (e.g., Stern, Tormos, Press, Pearlman, & Pascual-Leone, 2007) found that repetitive stimulation of the left or right dorsolateral prefrontal cortex was associated with symptom reduction in individuals with recurrent unipolar depression when compared with sham stimulation. These lines of research provide exciting evidence and hope that cognitive neuroscience will inform the prevention, diagnosis, and treatment of severe and disabling conditions of the brain and mind.

Advances in the fields of cognition and neuroscience also shed light on our understanding of brain processes such as learning and memory, which are critical to educational practices. Recent research topics include visual perception benefits accrued from playing complex video games (Green & Bavelier, 2003), focused attention on interventions for both children and parents, reading interventions during the development of language perception, and possible neural correlates of women's underperformance in math (e.g., Stevens and Neville, 2008; Varma, Mc Candliss, & Schwartz, 2008). Well suited to integrating the once disparate disciplines of

neuroscience and education, cognitive neuroscience is even elucidating neural algorithms for specific scholastic subject areas. For example, in the domain of mathematics, this approach has begun to identify the brain bases of numerical thinking. Behavioral and neuroimaging results suggest that children and adults share a “number sense,” that is, a system for representing approximate numerical magnitude (Dehaene, Spelke, Pinel, Stanescu, & Tsivkin, 1999; Jordan & Brannon, 2006). It has recently been found that this neural system is compromised in the approximately 5% of children who have developmental dyscalculia, a specific mathematical learning disability (Price, Holloway, Vesterinen, Rasanen, & Ansari, 2007).

Such neuroscientific findings encourage very early interventions to target deficits, even before children enter elementary grades. One such recent behavioral intervention is to play linear number board games akin to Chutes and Ladders, which was shown to boost numerical magnitude understanding in preschoolers who were at risk for later falling behind in mathematics (Ramani & Siegler, 2008). This approach is one example of how cognitive neuroscience is helping in the field of education by translating neuroscientific findings into cognitive interventions that can effectively be implemented at an early age.

Another interesting implication of cognitive neuroscience [5] is its intersection with the law (Gazzaniga, 2005). In a famous court case in 1982, John Hinckley, Jr., who had attempted to assassinate President Ronald Reagan, submitted CT scans indicating cortical atrophy in an attempt to gain a verdict of not guilty due to insanity. In a controversial decision, Hinckley’s defense ultimately succeeded (*U.S. v. Hinckley* 1982). Since this historical case, evidence based in cognitive neuroscience, albeit remaining highly controversial, has played an increasingly important role in the criminal justice system. For example, fMRI-based lie detection tests have [6][7] become a part of legal proceedings (Kozel, 2005; Rosenfeld, 2007), although empirical evidence for their reliability is still in question. While providing an illuminating example of the integration of cognitive neuroscience and the law, it is important to ensure that such progress does not compromise justice (Poldrack, 2008). Most important, the legal concept of responsibility should not be weakened by an endless flood of legal defenses attempting to reduce culpability on [8] the basis of subtle neural defects (Gazzaniga, 2005).

Another concern centers on the issue of privacy (Tovino, [9] 2007). Neuroimaging methods allow us to extract health-related information based on patterns of neural activity and brain structure. For instance, we currently have the ability [10] to predict cognitive decline (Small et al., 2008) and risk for [11] psychiatric illness (Phillips & Vieta, 2007) on the basis of the detection of biomarkers using neuroimaging. It is likely that the use of fMRI in the private sector will only increase in

the coming years. Laws to regulate the use of private health-related information and to protect the privacy of individuals will have to be enacted.

These are only a few of the ethical challenges faced by those whose job it is to update societal institutions and policies with the knowledge gained from cognitive neuroscience. The newly emerging field of neuroethics should play a vital role in protecting society from the detrimental effects or imprecise applications of neuroscience and must thoroughly address the difficult ethical dilemmas that arise.

To encourage public dialogue and awareness of the philosophical, ethical, and practical implications of neuroscientific research, U.S. president George H. W. Bush declared the 1990s to be the Decade of the Brain. Whether it was this proactive step on the part of the American government or the rapid and prolific development of the field of cognitive neuroscience, public interest in the brain has exploded. In the entire decade between 1980 and 1990, a mere 100 books were published related to cognitive neuroscience; this number increased tenfold during the Decade of the Brain to more than 1000 books. Since the year 2000, this figure has multiplied to over 4000 volumes on cognitive neuroscience in print! (as determined by a keyword search of “cognitive neuroscience” on www.amazon.com in June 2008). Many of these books were written for a lay audience and have become mass market paperbacks reaching a public that is fascinated by the brain—and rightfully so. Cognitive neuroscience has the potential to explain the neural processes underlying consciousness, free will, morality, sexuality, emotion—all of those seemingly ineffable qualities that set us humans apart from other animals. As a result, many new research findings have implications that reach far beyond the relatively small cognitive neuroscience research community. The unique position of cognitive neuroscience of being a rather public science cannot be taken lightly, as we have the potential to profoundly alter and reshape the perception of the human condition in the public eye.

The pressure to present complex empirical data and theories so that they are accessible to nonexperts has sometimes led to excessive reductionism in the popular media. Catchy headlines such as “Nose cells may help paralyzed to walk again,” “This is your brain on politics,” and “‘God spot’ researchers see the light in MRI study” attempt to generate interest in readers but provide inaccurate “just-so” explanations of brain function. Admittedly, it is difficult to balance the goal of providing straightforward answers to difficult questions with effective communication to a broad audience, even for those of us in the field. Consequently, we as researchers must work together with journalists, writers, and reporters in the media to recognize and embrace our responsibility to help experts, as well as nonexperts, understand and appreciate the pluralism of our data and of the human mind.

Cognitive neuroscience is an evolving discipline, and that is what makes it so exciting, but it also means that insights are sometimes fragmentary, methods suffer from shortcomings, and theories are often conflicting. Accurately representing and communicating these complexities will allow the public to see the passion but also the tireless effort of cognitive neuroscientists. We should therefore be eager to invite society on this exciting journey toward a deeper understanding of how the human brain creates a mind that has the potential to fall ill, to forget, or to lose sense but also to reason, to empathize, to dream, and to love.

REFERENCES

- ARZY, S., MOLNAR-SZAKACS, I., & BLANKE, O. (2008) Remembering the future, predicting the past: a neuroimaging study of mental time travel. *J. Neurosci.*, 28(25), 6502–6507.
- BOYLAN, C. B., BLUE, M. E., & HOHMANN, C. F. (2007). Modeling early cortical serotonergic deficits in autism. *Behav. Brain Res.*, 176(1), 94–108.
- CANLI, T., COONEY, R. E., GOLDIN, P., SHAH, M., SIVERS, H., THOMASON, M. E., et al. (2005). Amygdala reactivity to emotional faces predicts improvement in major depression. *NeuroReport*, 16(12), 1267–1270.
- CARLSON, T. A., SCHRATER, P., & HE, S. (2003). Patterns of activity in the categorical representations of objects. *J. Cogn. Neurosci.*, 15(5), 704–717.
- CASTELLANOS, F. X., MARGULIES, D. S., KELLY, C., UDDIN, L. Q., GHAFARI, M., KIRSH, A., et al. (2008). Cingulate-precuneus interactions: A new locus of dysfunction in adult attention deficit/hyperactivity disorder. *Biolog. Psychiatry*, 63(3), 332–337.
- COX, D. D., & SAVOY, R. L. (2003). Functional magnetic resonance imaging (fMRI) “brain reading”: Detecting and classifying distributed patterns of fMRI activity in human visual cortex. *Neuroimage*, 19(2, Pt 1), 261–270.
- CROCKETT, M. J., CLARK, L., TABIBIA, G., LIEBERMAN, M. D., & ROBBINS, T. W. (2008). Serotonin modulates behavioral reactions to unfairness. *Science*, 320(5884), 1739.
- DEHAENE, S., SPELKE, E., PINEL, P., STANESCU, R., & TSIVKIN, S. (1999). Sources of mathematical thinking: Behavioral and brain-imaging evidence. *Science*, 284, 970–974.
- FRIES, P., WOMELSDORF, T., OOSTENVeld, R., & DESIMONE, R. (2008). The effects of visual stimulation and selective visual attention on rhythmic neuronal synchronization in macaque area V4. *J. Neurosci.*, 28(18), 4823–4835.
- FUCHS, E., & FLUGGE, G. (2006). Experimental animal models for the simulation of depression and anxiety. *Dialogues Clin. Neurosci.*, 8(3), 323–333.
- GERSTEN, R., & CHARD, D. J. (1999). Number sense: Rethinking arithmetic instruction for students with mathematical disabilities. *J. Special Educ.*, 33, 18–28.
- GOBBINI, M. I., & HAXBY, J. V. (2007). Neural systems for recognition of visually familiar faces. *Neuropsychologia*, 45(1), 32–41.
- GREEN, C. S., & BAVELIER, D. (2003). Action video games modify visual attention. *Nature*, 423(6939), 534–537.
- GUNNERSEN, J. M., KIM, M. H., FULLER, S. J., DE SILVA, M., BRITTO, J. M., HAMMOND, V. E., et al. (2007). Sez-6 proteins affect dendritic arborization patterns and excitability of cortical pyramidal neurons. *Neuron*, 56(4), 621–639.
- HARIRI, A. R., MATTAY, V. S., TESSITORE, A., KOLACHANA, B., FERA, F., GOLDMAN, D., EGAN, M. F., & WEINBERGER, D. R. (2002). Serotonin transporter genetic variation and the response of the human amygdala. *Science*, 297(5580), 400–403.
- HOUWELING, A. R., & BRECHT, M. (2008). Behavioural report of single neuron stimulation in somatosensory cortex. *Nature*, 451(7174), 65–68.
- HUNG, A. Y., UTAI, K., SALA, C., VALTSCHANOFF, J. G., RYU, J., WOODWORTH, M. A., et al. (2008). Smaller dendritic spines, weaker synaptic transmission, but enhanced spatial learning in mice lacking Shank1. *J. Neurosci.*, 28(7), 1697–1708.
- IACOBONI, M., MOLNAR-SZAKACS, I., GALLESE, V., BUCCINO, G., MAZZIOTTA, J. C., & RIZZOLATTI, G. (2005). Grasping the intentions of others with one's own mirror neuron system. *Publ. Library Sci. Biol.*, 3(3), 529–535.
- JORDAN, K., & BRANNON, E. (2006). The multisensory representation of number in infancy. *Proc. Natl. Acad. Sci.*, 103, 3486–3490.
- KAWASAKI, K., & SHEINBERG, D. L. (2008). Learning to recognize visual objects with microstimulation in inferior temporal cortex. *J. Neurophysiol.*, 100(1), 197–211.
- KENSINGER, E. A., PIGUET, O., KRENDL, A. C., & CORKIN, S. (2005). Memory for contextual details: Effects of emotion and aging. *Psychol. Aging*, 20(2), 241–250.
- MAJEWSKA, A., & SUR, M. (2006). Plasticity and specificity of cortical processing networks. *Trends Neurosci.*, 29, 323–329.
- MARTIN, A. (2007). The representation of object concepts in the brain. *Annu. Rev. Psychol.*, 58, 25–45.
- MCAARTHUR, R., & BORSINI, F. (2006). Animal models of depression in drug discovery: A historical perspective. *Pharmacol. Biochem. Behav.*, 84(3), 436–452.
- MCGLASHAN, T. H., & HOFFMAN, R. E. (2000). Schizophrenia as a disorder of developmentally reduced synaptic connectivity. *Arch. Gen. Psychiatry*, 57(7), 637–648.
- MITCHELL, J. P. (2008). Contributions of functional neuroimaging to the study of social cognition. *Curr. Dir. Psychol. Sci.*, 17, 142–146.
- MUNAFO, M. R., BROWN, S. M., & HARIRI, A. R. (2008). Serotonin transporter (5-HTTLPR) genotype and amygdala activation: A meta-analysis. *Biol. Psychiatry*, 63(9), 852–857.
- NORMAN, K. A., POLYN, S. M., DETRE, G. J., & HAXBY, J. V. (2006). Beyond mind-reading: Multi-voxel pattern analysis of fMRI data. *Trends Cogn. Sci.*, 10(9), 424–430.
- O'CONNOR, D. H., FUKUI, M. M., PINSK, M. A., & KASTNER, S. (2002). Attentional modulates responses in the human lateral geniculate nucleus. *Nature Neurosci.*, 5(11), 1203–1209.
- PLATEK, S. M., KEENAN, J. P., & SHACKELFORD, T. K. (2006). *Evolutionary cognitive neuroscience*. Cambridge, MA: MIT Press.
- POLDrack, R. A. (2008). The role of fMRI in cognitive neuroscience: Where do we stand? *Curr. Opin. Neurobiol.*, 18(2), 223–227.
- PRICE, G. R., HOLLOWAY, I., VESTERINEN, N., RASANEN, P., & ANSARI, D. (2007). Impaired parietal magnitude processing in developmental dyscalculia. *Curr. Biol.*, 17, R1023–R1024.
- RAICHLE, M. E., MACLEOD, A. M., SNYDER, A. Z., POWERS, W. J., GUSNARD, D. A., & SHULMAN, G. L. (2001). A default mode of brain function. *Proc. Natl. Acad. Sci. USA*, 98(2), 676–682.
- RAMANI, G. B., & SIEGLER, R. S. (2008). Promoting broad and stable improvements in low-income children's numerical knowledge through playing number board games. *Child Dev.*, 79, 375–394.

14

- RAMUS, F. (2006). Genes, brain, and cognition: A roadmap for the cognitive scientist. *Cognition*, 101(2), 247–269.
- RIZZOLATTI, G., & CRAIGHERO, L. (2004). The mirror-neuron system. *Annu. Rev. Neurosci.*, 27, 169–192.
- SCHACTER, D. L., ADDIS, D. R., & BUCKNER, R. L. (2007). Remembering the past to imagine the future: The prospective brain. *Nature Rev. Neurosci.*, 8(9), 657–661.
- STERN, W. M., TORMOS, J. M., PRESS, D. Z., PEARLMAN, C., & PASCUAL-LEONE, A. (2007). Antidepressant effects of high and low frequency repetitive transcranial magnetic stimulation to the dorsolateral prefrontal cortex: A double-blind, randomized, placebo-controlled trial. *J. Neuropsychiatry Clin. Neurosci.*, 19(2), 179–186.
- STEVENS, C., & NEVILLE, H. (2008). *Experience shapes human brain development and function: A framework for planning interventions for children at-risk for school failure*. Paper presented at AAAS meeting, Boston, MA.
- VARMA, S., McCANDLISS, B. D., & SCHWARTZ, D. L. (2008). Scientific and pragmatic challenges for bridging education and neuroscience. *Educ. Res.*, 37, 140–152.