CHAPTER 1

Progress in Attention Research 2004–2011

Michael I. Posner

The pace of attention research has accelerated since the previous edition of this volume was published in 2004. Among the major trends are (1) further integration of research in which behavioral, imaging, cellular, and genetic methods are combined; (2) important breakthroughs in imaging the developing brain; (3) new applications of attentional theory to illuminate psychopathology; (4) proposed interventions to improve poor attention and normal aging.

I have continued to group the chapters under the general headings of Cognitive Science, Imaging, Neuroscience, Development, and Deficits and Interventions, but it becomes increasingly difficult to keep them in place as methods are combined and developmental or evolutionary perspectives are applied to adult studies. For each of these topics I have tried to indicate places where advances have occurred and the new research opportunities they offer.

Cognitive Science

A major trend in cognitive studies is to develop explicit models that can be used to summarize previous findings and to predict new ones. These models often focus on individual tasks, but hopefully in the future they will be applied more generally to encompass the whole of attention. Modeling usually begins by trying to define the domain to which the model applies. Klein and Lawrence (Chapter 2) develop a taxonomy of attention tasks by considering attention to space and time separately for exogenous and endogenous cues. The type of endogenous cue is quite specific in this chapter, usually involving the use of an arrow or a verbal instruction, but the problem of how an internal "goal tree" of current concerns operates to bias attention toward relevant environmental events remains for future studies.

Chapter 3, by Huang and Pashler, describes a Boolean model for a set of tasks that involves both exogenous and endogenous attention to spatial locations or object features. The Boolean map provides a method of access that is richer than a spatial location and provides a theoretical framework for the idea of salience maps that have been developed in primate studies (e.g., Bisley & Goldberg, 2010).

Frequently, models are designed to mirror performance in a single cognitive task. One task that is used in several chapters is the Attention Network Test (ANT). This test is designed to provide measures of different attention networks and is discussed further in Chapters 6, 9, 13, 20, 21, 25, and 31. In Chapter 4, Wang, Lin, and Fan present both symbolic and connectionist models of the task. The task purports to provide a somewhat independent measure of the efficiency of three attentional networks, but how these networks function together in a coordinated fashion during the complex natural tasks of daily life is still largely a mystery.

In Chapter 5, Humphreys and Mavritsaki expand the model-building effort by explicit use of neuroimaging data in the study of visual search. They argue persuasively that using a combination of behavioral and imaging input to build models is needed to further develop a cognitive neuroscience of attention. Interestingly, their imaging data point to the key role of the right temporal parietal junction, a brain area already identified as a unique contributor to the disengaging of attention (see also Chapter 9).

While the early chapters in Part I deal mainly with orienting to sensory events, where the field has advanced the most, the last few chapters raise higher-level issues of executive control. The areas of executive control and self-regulation (see the Development section) are crucial ones for the future of the field. In Chapter 6, Fuentes and colleagues begin this discussion by pointing out some of the similarities between orienting to sensory events and to semantic memory. Both of these functions seem to involve similar component operations, such as engaging and disengaging the focus of attention. As Carter and Krug (Chapter 7) point out, conflict between responses is ubiquitous, because the brain computes many simultaneous functions, the output of which could conflict with current goals. When the brain is viewed in terms of its many simultaneously active networks, the problem of regulating output with respect to current goals becomes a central issue. Carter and Krug argue that a brain network involving the anterior cingulate is involved in monitoring this conflict and in working with other brain areas to prevent conflicting behaviors. It is this aspect of executive control that links this part with Parts II and IV on Imaging and on Development and represents an important future for attention studies.

The link between attention and working memory for spatial locations is the topic of Chapter 8 by Ester, Vogel, and Awh. Close links between attention and memory have been proposed from some of the earliest papers on working memory (e.g., Baddeley & Hitch, 1974). In the current chapter, a correlation is reported between the number of items that can be tracked by attention and the number held in store during working memory tasks. As stated by the authors of Chapter 8, "we propose that a *common discrete resource* mediates both the selection and storage of visual information. This discrete resource enables the simultaneous selection or storage of a limited number of individuated object representations." This chapter points the way to important research linking attention to individual and group differences, and these differences are discussed further in Part IV on Development and Part V on Deficits.

Imaging

Imaging has opened a distinct level of analysis in terms of brain networks, somewhere between the behavioral models of cognitive science and the cellular and genetic orientation of neuroscience. The idea of brain networks underlying cognition has probably been most advanced in the study of attention. In most of the chapters in Part II the form of attention studied involves orienting to sensory (usually visual) objects, often during search for a target. However, Chapters 11 and 13 point toward imaging studies of other forms of attention.

As Shulman and Corbetta say in Chapter 9, "Single-unit, event-related potential, transcranial magnetic stimulation, and neuroimaging studies have investigated the detailed characteristics of the frontal and parietal components of this system." Shulman and Corbetta highlight the dorsal and ventral attention networks that are active during orienting to sensory events; however, these same regions remain connected during rest (see Fair et al., Chapter 20). The right temporal–parietal junction (TPJ) appears to be a very specialized region that plays a role in reorienting away from an attended location, irrespective of the direction of new stimuli. The TPJ also appears to be the most frequently damaged brain area in patients who exhibit neglect.

The visual system can extract objects from cluttered visual scenes. The orienting system described by Shulman and Corbetta influences the visual system's response to objects within scenes but exactly how strong an influence is possible? Reddy and Kanwisher, in Chaper 10, review studies of multivoxel pattern recognition routines to quantify this influence. The method of combining voxels from different regions illustrates the use of magnetic resonance imaging (MRI) to peer into the microcircuitry of visual recognition.

The influence of many visual areas on the recognition of an individual pattern in a cluttered field suggests that even relatively localized processes such as visual recognition may involve multiple areas working together. As we move forward in the brain to frontal areas, this principle becomes even more important, as Duncan and Manly point out in Chapter 11. The function of a frontal area depends on the task structure. As the person attends to different aspects of the task, many frontal areas become activated in accord with task demands. Duncan and Manly also propose to account for individual differences in the ability to solve problems by identifying a set of areas, including prefrontal and cingulate areas, involved in many tasks that load upon the general (*g*) factor of intelligence tests.

Attention allows the anticipation of where a target will occur and also when it will occur, as discussed by Nobre and colleagues in Chapter 12. They report that temporal anticipation does not amplify the early P1 wave of the event-related potential (ERP), which is normally enhanced by attending to locations. This may be because a warning signal does not change processing along the ventral ("what" pathway) but acts to enhance the speed at which that information can be attended (Posner, 2008). This relatively late influence could reflect the distribution of norepinepherine input, which is strong in the parietal lobe but does not directly modulate the ventral pathway (Morrison & Foote, 1986). Nobre et al. argue that oscillatory activity may serve as one mechanism by which temporal information influences processing in remote brain regions.

A major development of work with MRI is the measurement of white matter both by functional connectivity (correlations in the blood-oxygenation-level-dependent [BOLD] signal between brain areas) and diffusion tensor imaging (DTI). In Chapter 13, McCandliss shows that measurements of fractional anisotropy (FA) of different white matter tracts using DTI are correlated with performance of separate attentional networks as measured by the ANT. For example, the executive network, as measured by the difference in reaction time (RT) between congruent and incongruent flankers, is correlated with FA measures in the anterior corona radiata, a white matter tract connecting the anterior cingulate to frontal and parietal areas. The measure of FA has been shown to be affected by the degree of myelination occuring in early development (see also Fair et al., Chapter 20), but other factors also contribute.

Most of the attention studies in this volume and in the literature use briefly presented stimuli flashed to the person, but of course real-life scenes can be examined over many seconds or minutes. ERPs to an object can be sustained by flickering a stimulus at a given frequency. When different objects within the scene are flickered at different rates, the resulting ERPs allow the experimenter to determine where the viewer is attending. A tutorial on how this method can be used to examine the role of attention in scene perception is given in Chapter 14 (Andersen et al.).

Neuroscience

The effort to measure activity in the brain with both temporal and spatial precision is a continually improving process. In Chapter 15, Woodman and Schroeder combine imaging and cellular recording to produce measures of ERPs together with extracellular recording in alert monkeys during visual search. This chapter links the largely human work using functional MRI (fMRI) in Part II with the primate studies discussed in Part III. The increased integration between human, primate, and even rodent studies augurs well for the achievement of a detailed understanding of the microcircuits related to attention.

Neuroscience studies typically involve aspects of the microcircuitry to examine neuronal firing under various conditions—in this volume usually as a function of attention. Miller and Buschman (Chapter 16) study alert monkeys engaged in visual search. They examine the brain network involving the frontal eye fields and parietal areas discussed by Shulman and Corbetta in Chapter 9 (see also Chapters 17 and 18, below). By recording from indwelling electrodes at several sites, they are able to argue that bottom-up search activates the parietal areas first, whereas top-down control activates the frontal eye field earlier than the parietal areas. This finding fits the distinction often made in the human literature between voluntary and stimulus driven attention shifts (see Chapter 2, e.g.). Chapter 16 shows clearly that cells in the frontal eye field fire in relation to covert shifts of attention without there being any hint of eye movements.

Studies of cellular recording apply to a long-continued dispute about how eye movements relate to covert attention shifts. We know from behavioral and fMRI work that shifts of attention can occur without eye movements, just as reported by Miller and Bushman in Chapter 16. However, one theory is that the covert shift involves the preparation of an eye movement whether or not it is executed (Rizzolatti et al., 1987). Extensive behavioral work has demonstrated conflicting findings on this point. Data from fMRI (Corbetta, 1998) have revealed a striking similarity between the anatomy of covert attention shifts and eye movements. One of the areas involved in both saccades and covert attention is the frontal eye fields. Schall and Thompson, in Chapter 17, argue that there are separate populations of cells intermixed within the frontal eye fields. The visual cells are more active with covert shifts, whereas movement cells are more active during the generation of saccades. However, in Chapter 18, Moore and colleagues argue that the populations are not distinct and that most cells have both visual and movement functions. They report that covert attention shifts and saccade preparation interact and that under some circumstances, the attention shifts appear to control the saccade trajectories, and in other situations, the reverse. Thus despite many behavioral, fMRI, and now cellular approaches, the exact relation between eye movements and covert attention shifts seems to remain unsettled.

Although psychologists would probably all agree that attending to something is important for at least some forms of later memory, there have been few attempts to pin down the pathways by which attention exerts its influence on the likelihood of later performance. Using a rodent model, Rowland and Kentros, in Chapter 19, point to indirect pathways from cingulate to areas of the midtemporal lobe as important in the process of stabilizing neuronal activity in the formation of place memories. Dopaminergic input from the ventral tegmental area appears to have an important influence on this process.

Development

The ability to examine connectivity between brain areas when the person is at rest has greatly enhanced studies of human brain development. It is very difficult to design tasks that allow one to study the brain at all ages from infancy to adulthood when participants are performing common cognitive operations. However, resting is a state common to all ages. While we have known for many years that white matter changes over development as myelination occurs, in Chapter 20 (Part IV), Fair and colleagues provide graphs of connectivity patterns that illustrate details of the changing pattern between children and adults. Two of these networks are closely connected to the acts of orienting to sensory events and executive control. These two networks are more closely integrated early in life and achieve separation in adulthood. In addition, long connections between remote brain areas become more common in development. This chapter provides evidence of a change in connectivity of the midfrontal area even late in childhood.

Recent work using the resting state has traced functional connectivity even in infants (Gao et al., 2009). In Chapter 21, Berger and colleagues present another way to examine the development of the human anterior cingulate through its importance in error detection. The chapter shows that the cingulate is active in the detection of error even at 7 months, but that the full function of the network in correcting error continues to develop. They also show how the theta rhythm detected at midfrontal areas can be used to trace the development of control mechanisms related to this network.

The detection of error is at once both cognitive and emotional, and a major function of the network involving the anterior cingulate is regulation of emotion. Chapter 22, by Bell and Calkins, uses early control of distress to show how this network influences the regulation of emotion and to trace individual differences in emotion regulation. Emotion regulation is a key aspect of development, and those individuals who have difficulty with it are at risk for later behavior problems (see also next section on deficits). These studies point to the importance of understanding early brain development. The connectivity studies give us a rich picture of how brain connectivity changes; however, we need to link these changes to the early development of self-regulation and to understand what types of parental and child training might serve to prevent poor outcomes for children low in regulatory skill.

Chapter 23, the final chapter in Part IV, by Deater-Deckard and Wang, is related both to the emphasis on brain development and self-regulation in this section and to the tutorial on genetic methods in Chapter 27. These authors report that attentive behavior shows a general increase up to age 7 and then levels off or declines. By use of a large population of twins and siblings, they show that both genes and environment contribute to these developmental trends (see also Chapter 27 on genes and attention-deficit/hyperactivity disorder [ADHD]). They trace the role of the 7-repeat allele of the dopamine 4 receptor gene, which has been most frequently associated with ADHD, during the early years of schooling and find that the influence of two copies of this allele on scores of inattention increases dramatically between grades 1 and 5. This allele has also been reported to make children more susceptible to influence by their environment and to undergo positive selection in human development (Rothbart et al., 2011). Because children with the 7-repeat allele are strongly influenced by the environment, it could be that the reported increase in their inattentive behavior between grades 1 and 5 is related to the increasing influence of peers at this age.

Deficits and Interventions

In this second edition there is much more emphasis on application of attention results to the etiology, genetics, diagnosis, and treatment of a variety of disorders. It may be surprising to many clinicians how close cognitive and clinical issues have become. The disorders discussed in this section range from purely genetic ones through those in which the environment may play the most prominent role. Although the causes of these disorders may not relate specifically to attention, brain networks related to attention seem to play an important role in understanding the disorder and have the potential to inform treatment or prevention efforts.

In Chapter 24 (Part V), Casey and Riddle emphasize the way in which disrupted mechanisms of self-regulation (also discussed in Chapters 21 and 22) contribute to several disorders, including ADHD and schizophrenia. They distinguish between signaling and implementation of control systems and show how the breakdown of these functions is related to various disorders.

In Chapter 25, Townsend and collegues provide an extensive treatment of the role of attention in autism. Surprisingly, the orienting network seems to be in deficit, not merely when the child is involved in social situations, but also in abstract experiments involving spatial cues with little or no social context. They argue that autistic orienting is driven heavily by top-down mechanisms and is less influenced by learned associations than is the case with typically developing individuals.

Recent studies using the ANT have (Fan et al., 2002) have shown both alerting and executive deficits in children with attention deficit disorder (Johnson et al., 2008). Halperin and Schultz (2006) present a developmental model in which early alerting deficits result in later executive deficiencies. In this volume Bush (Chapter 26) explores the role of the cingulate together with frontal and parietal areas in ADHD. Using a multisource interference task to test deficits in connectivity within a wide network of brain areas he relates to ADHD, Bush reports deficits in dorsal anterior cingulate gray matter in adults with ADHD. He also reports preliminary efforts to use relaxation and meditation as possible behavioral treatments for ADHD.

Attention depends on anatomical networks common to all people. These common attention networks must be created by genes that influence their development. In the first edition of this book, several studies were included that related individual differences in attention to genetic polymorphisms through the study of candidate genes. These candidate genes were shown to relate to performance in specific attentional tasks involving the orienting and executive networks. These chapters remain relevant. In Chapter 27, Arcos-Burgos and Muenke take another important step in relating genes to attention: They examine the role of genomewide associations in detecting genes that might contribute to attention deficits. In the process, they provide a guide to websites that help in the search for relevant genetic pathways, and they locate a gene that appears to be important in ADHD.

The effort to find the most analytic tasks for activation of brain areas and for the fine-grain description of performance is a major feature of the study of the role of attention in various disorders. In Chapter 28, Ridderinkoff and colleagues discuss how to analyze distributions of RT to highlight disorders involving the control of conflict. They apply this method to Parkinson's disease as well as to ADHD and other disorders.

Much work on psychopathy as a disorder has emphasized the overall lack of empathy, but Newman and Baskin-Summers (Chapter 29) show that attention to features of the environment also plays an important role in its etiology. Psychopaths seem to miss features of the environment when they are not central to the task. This may help account for their relative insensitivity to cues concerning their victims. The authors think that the reorienting mechanisms discussed by Shulman and Corbetta (Chapter 9) may show a deficit in psychopaths. In addition, the authors point out that the psychopathic state may shed some light on important distinctions in the study of self-regulation.

The 22q11 syndrome involves the deletion of several genes, including the catechol-*O*-methyltransferase (COMT) gene, related to the ability to deal with conflict. Profound physical as well as psychological deficits arise from the deletion of these genes. In previous chapters, some of which are by Simon, the deficits in these children were related to executive attention and the failure to do well in conflict tasks. However, in Chapter 30, Simon and Luck consider the possibility that a more profound deficit occurs in the ability of these children to represent fine-grain spatial and temporal information. This deficit may account for many of the number-processing and attentional deficits that research has uncovered.

The final two chapters deal with the possibility that training exercises might change the brain and improve or even prevent deficits due to attention. O'Connell and Robertson (Chapter 31) review evidence for various kinds of brain plasticity that might be induced by cognitive training. Despite the evidence for such plasticity, the data on specific forms of training that could generalize are still quite sparse. Partly this is due to the relatively few studies devoted to this topic, and also to the difficulty of appropriate controls. Despite these problems, some theoretical ideas, arising from research on brain mechanism of attention, have given rise to practical exercises useful in the remediation of aspects of neglect (see also Shulman and Corbetta, Chapter 9). With the large number of older adults in Western populations, a likely target for training exercises has been reduction or prevention of dementia. O'Connell and Robertson also cite evidence for the usefulness of aerobic exercise. Some recent studies suggest that mental exercise can also improve brain function in older adults, and that a combination of physical and mental exercise might be particularly useful on a broad range of cardiac, respiratory and brain systems.

Klingberg has done important work on training working memory in children suffering from ADHD. In Chapter 32 he seeks to relate improvement in working memory to underlying changes in attention networks. There are, of course, several forms of working memory, and Klingberg seeks to identify the link between visual–spatial working memory and attention. He argues that the link arises in their common need to hold locations in mind (see also Chapter 8). This training generalizes to other tasks that involve spatial-like mechanisms, such as the use of a number line in dealing with the representation of quantity.

This book presents a series of snapshots from researchers at the forefront of their respective fields. It is the goal of this overview, and of the book as a whole, to aid the reader in transforming these static pictures into a movie that takes them from the past toward a future, in which method and theory link the various levels of analysis into an overall cumulative account of attention.

REFERENCES

Baddeley, A., & Hitch, G. (1974). Working memory. In G. A. Bower (Ed.), *Recent advances in learning and motivation* (pp. 47–90). New York: Academic Press.

Bisley, J. W., & Goldberg, M. E. (2010). Attention, intention, and priority in the parietal lobe. *Annual Review of Neuroscience, 33*, 1–21.

Corbetta, M. (1998). Frontoparietal cortical networks for directing attention and the eye to visual locations: Identical, independent, or overlapping neural systems? *Proceedings of the National Academy of Sciences of the USA, 95*, 831–838.

Fan, J., McCandliss, B. D., Sommer, T., Raz, M., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience, 3*(14), 340–347.

Gao, W., Zhu, H., Giovanello, K. S., Smith, J. K., Shen, D., Gilmore, J. H., et al. (2009). Evidence on the emergence of the brain's default network from 2-week-old to 2-year-old healthy pediatric subjects. *Proceedings of the National Academy of Sciences of the USA, 106*, 6790–6795.

Halperin, J. M., & Schulz, K. P. (2006). Revisiting the role of the prefrontal cortex in the pathophysiology of attention-deficit/hyperactivity disorder. *Psychological Bulletin, 132*, 560–581.

Johnson, K. A., Robertson, I. H., Barry, E., et al. (2008). Impaired conflict resolution and alerting in children with ADHD: Evidence from the ANT. *Journal of Child Psychology and Psychiatry, 49*, 1339–1347.

Morrison, J. H., & Foote, S. L. (1986). Noradrenergic and serotonergic innervation of cortical, thalamic, and tectal visual structures in Old World and New World monkeys. *Journal of Comparative Neurology, 243*, 117–128.

Posner, M. I. (2008). Measuring alertness. In D. W. Pfaff & B. L. Kieffer (Eds.), *Molecular and biophysical mechanisms of arousal, alertness, and attention* (pp. 193–199). Boston: Blackwell.

Rizzolatti, G., Riggio, L., Dascola, I., & Umilta, C. (1987). Reorienting attention across the horizontal and vertical meridians: Evidence in favor of the premotor theory of attention. *Neuropsychologia, 25*, 31–40.

Rothbart, M. K., Sheese, B. E., Rueda, M. R., & Posner, M. I. (2011). Developing mechanisms of self-regulation in early life. *Emotion Review, 3*(2), 1–7.