Attention in cognitive neuroscience: An overview

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PART A

INTRODUCTION

CHAPTER 1

GUIDES TO THE STUDY OF ATTENTION

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This volume presents a modern look at the field of attention. The identities of the editors of this volume suggest why it and they can serve as guides to current and future research. Kia Nobre is a leader in the use of neuroimaging to study attention largely in humans, while Sabine Kastner bridges neuroimaging approaches in both humans and monkeys to the cellular approach of neurophysiology. These two methods are increasingly integrated in empirical research and theory in the field. They have selected a very strong set of authors to provide guidance on theory and empirical research on attention. In this foreword I try to trace the background of these methods within the field of attention, look briefly at the current state of integration as represented by the chapters of this Handbook, and speculate on future developments.

Historical Background

In the mid-twentieth century Moruzzi and Magoun (1949) began using animal models to explore aspects of attention. They studied the midbrain reticular system as the mechanism of arousal. In their work attention involved a state in which the animal was aroused from coma or sleep and then demonstrated both spontaneous integrated activity and processing of sensory stimuli.

Hubel and Wiesel (1968) used microelectrodes to probe the structure of the visual system. Before this method could be applied to attention, however, it was necessary to adapt the microelectrode technique to alert animals. This was accomplished in the early 1970s and applied by Mountcastle (1978) and Wurtz, Goldberg, and Robinson (1980) to examine mechanisms of orienting to visual objects in the superior colliculus and parietal lobe. Their findings suggested the importance of both of these areas to a shift of visual attention. It had been known for many years that patients with lesions of the right parietal lobe could suffer from a profound neglect of space opposite the lesion. The findings of 'attention-related cells' in the posterior parietal lobe of alert monkeys suggested that these cells might be responsible for the clinical syndrome of neglect.

An impressive result from the microelectrode work was that the time course of parietal cell activity seemed to follow a visual stimulus by 80–100 ms. Beginning in the 1970s, Hillyard (van Voorhis and Hillyard 1977) and other investigators explored the use of scalp electrodes to examine time differences in neural activity between attended and unattended visual locations. They found that early parts of the visual event-related potential (ERP) showed changes due to attention starting at about 100 ms after input. These findings showed likely convergence of the latency of psychological processes as measured by ERPs in human subjects and cellular processes measured in alert monkeys. These results were an important development for mental chronometry (i.e. the study of the time course of information processing in the human brain) because they suggested that scalp recordings could accurately reflect the underlying temporal structure of brain activity.

In the late 1980s, the Washington University School of Medicine was developing a centre for neuroimaging using positron emission tomography (PET). The centre was led by Marc Raichle. These studies helped establish neuroimaging as a means of exploring brain activity during cognitive functions in general and attention in particular (Corbetta and Shulman 2002; Posner and Raichle 1994, 1998). In general, these studies showed that most cognitive tasks, including those that are designed to explore mechanisms of attention, have activated a small number of widely scattered neural areas.

The findings from neuroimaging that cognitive tasks involve a number of different anatomical areas led to an emphasis on tracing the time dynamics of these areas during tasks involving attention. Because shifts of attention can be so rapid, it is difficult to follow them with hemodynamic imaging. To fill this role, algorithms were developed (Scherg and Berg 1993) to relate the scalp distribution recorded from high density electrical or magnetic sensors on or near the skull to brain areas active during hemodynamic imaging (see Dale et al. 2000, for a review). In some areas of attention there has been extensive validation of these algorithms (Heinze et al. 1994), and they allow precise data on the sequence of activations during the selection of visual stimuli (see Hillyard, Di Russo, and Martinez 2004, for a review). The combination of spatial localization with hemodynamic imaging and temporal precisions from electrical or magnetic recording has provided an approach to revealing the dynamic operations of the networks underlying attention in humans that fit very well with the use of cellular recording in monkeys. In current research these methods have become increasingly integrated as made clear by this Handbook.

Current State of Research

Theory

This volume presents nine chapters on theory related to attention. The chapters include world leaders in the field. The first six chapters (section B; Chs. 2–7) are mainly in verbal form while the remaining three (section F; Chs. 38–40) are computational. Taken together these chapters develop theoretical methods that summarize empirical findings and data concerning the localization, connectivity, and time course of a wide variety of attentional tasks. The chapters present a comprehensive view of the current state of theory in this field.

Empirical studies

This volume makes a distinction between orienting towards locations in empty space (section B; Chs. 8–19) and orienting to objects that occupy that space (section C; Chs. 21–25). Sections B and C summarize major results in this field. While it is unusual for people to operate in a space without objects, the empty fields discussed in section B allow one to concentrate on the mechanisms of top-down influence without having to consider at the same time the structure of the perceptual field. Section C provides the important constraints that a context of multiple distractors and multiple targets provide.

Section D deals with how attention relates to voluntary control of motor activity (Ch. 26), working memory (Ch. 30), executive functions (Chs. 28–29), emotion (Ch. 27), and consciousness (Ch. 31). These are all important functions of cognition in which attention is involved along with other brain systems. It is not always easy to disentangle these multiple processes within complex task, but these chapters provide a summary of current efforts to do so.

Development and disorders

Although our chapter on development of attention networks is in section B (Ch. 20) and section E has chapters on ageing (Ch. 36) and developmental disorders (Ch. 37), the three can be put together as a summary of lifespan typical and atypical development. While very early development depends heavily on spatial orienting, it is clear that what develop in childhood are more general control networks that allow for self-regulation. The developmental process continues throughout life so that it is probably not completely appropriate to consider ageing as a disorder, although declines in function are clearly involved.

Disorders ought to be viewed in relation to typical development. Three chapters in section D deal mainly with neurological disorders (Chs. 32–34). Disorders involving clear cases of brain injury from stroke, tumour, or closed head injury provide important clues to critical brain areas important for attention.

Future of Research

Although the job of predicting the future of the field is mainly left to Ch. 41 in section H, here I provide some speculations on developments towards the integration between cellular and systems approaches.

Networks

New methods have greatly reduced the gap between cellular and synaptic mechanisms and systems approaches to the field of attention. On the one hand, imaging reveals the brain areas and connections important at rest and during cognitive activity, while on the other hand multiple electrodes allow simultaneous recording from many neurons and brain areas. This has allowed modern theories to concentrate on a detailed account of how networks control the flow of information.

It is altogether likely that new methods will be developed. For example, within the last few years magnetic resonance imaging has been expanded to view white matter connections (Behrens and Sporns 2012) and to reveal networks active during the resting state (Raichle 2009).

The development of optogenetic methods provides the opportunity to view and manipulate cells at the millisecond level in appropriate organisms (Deisseroth 2011). This invasive technology is not appropriate for humans, but starting with algae it has progressed to primates. Further ingenious application of genomics to imaging may eventually allow the complete integration of cellular with systems level analysis even within the human brain.

A fascinating new method with interesting links to the study of attention involves the use of video games to open the critical period usually involved in vision (Li, Ngo, Nguen, and Levi 2011). For many years it was believed that there is an early period in which visual input is needed in order to avoid loss of function. The video games may have increased cholinergic activity associated with visual orienting thus allowing better plasticity beyond the critical period. This has led to speculations that cholinergic agonists might help improve plasticity of visual function (Rokem and Silver 2010).

Evolution

Currently the cellular versus systems approach overlaps somewhat with human versus animal studies. While there is convincing evidence that some forms of attention are present in fruit flies (Miller, Ngo, and van Swinderen 2012) and thus likely throughout the animal kingdom, many forms (e.g. control of language) are unique or are nearly unique to humans. In areas such as orienting to visual objects monkeys and even rodents have been important for understanding the anatomy and neurochemistry of attention.

Even when human control is less similar to animal models the studies may provide an important perspective on where human abilities come from. An important current case is the role of Von Economo cells present in the human insula and anterior cingulate in top-down control of emotion and cognition (Seeley et al. 2012). The evolution of these cells in social animals and non-human primates may provide an important perspective on the development of self-regulation in humans. With new knowledge of genetics the evolutional approach will doubtless advance in the future.

Individuality

Most work on attention and most of the chapters of this volume deal with the forms of attention common to all people. However, the network approach does provide a natural link between universal properties of attention and individual differences.

The efficiency of the neural network underlying attention may be the reason that individuals differ in attention. In part, these differences in efficiency are due to genetic polymorphisms (see chapter 20 for a current discussion). The interaction of these polymorphisms with training and other environmental influences may provide new insight into how various forms of training may change gene expression and thus the efficiency of attention networks. Already it is possible to change connectivity with some forms of training (Tang and Posner 2009) and thus the interaction of training with genetics is likely to provide important future perspectives on child rearing and education (van Ijzendoorn et al. 2011).

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