Models of Working Memory: Mechanisms of Active Maintenance and Executive Control

This volume offers a much-needed forum for systematically comparing and contrasting existing models of working memory. It does so by asking each contributor to address the same comprehensive set of important theoretical questions on working memory. The answers to these questions provided in the volume elucidate the emerging general consensus on the nature of working memory among different theorists and crystallize incompatible theoretical claims that must be resolved in future research. As such, this volume serves not only as a milestone that documents the state of the art in the field but also as a theoretical guidebook that will likely promote new lines of research and more precise and comprehensive models of working memory.

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MODELS OF WORKING MEMORY

Mechanisms of Active Maintenance and Executive Control

Edited by

AKIRA MIYAKE AND PRITI SHAH

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In memory of my father

A.M.

For my parents

P.S.

Preface

Without doubt, working memory is one of the "hottest" topics in cognitive psychology and cognitive neuroscience. Since the publication of Baddeley's (1986) landmark book, several monographs and edited volumes that explore various aspects of working memory have been published (e.g., Gathercole, 1996; Gathercole & Baddeley, 1993; Logie, 1995; Logie & Gilhooly, 1998; Richardson, Engle, Hasher, Logie, Stoltzfus, & Zacks, 1996; Vallar & Shallice, 1990). Also, at least four journals have published a special issue on this topic (*International Journal of Behavioral Development,* 1994; see also de Ribaupierre & Hitch, 1994; *Memory & Cognition,* 1993; *Neuropsychology,* 1994; *Quarterly Journal of Experimental Psychology,* 1996), and another is also planning to publish a special section in 2000 (*Journal of Experimental Psychology: General*). In July of 1994 – 20 years after the publication of the seminal article on working memory that defined the field (Baddeley & Hitch, 1974) – an international conference specifically dedicated to working memory was held in Cambridge, UK, bringing together more than 200 researchers from across the world.

Working memory is also one of the most intensively studied areas in a new emerging field of study, cognitive neuroscience. Reflecting the dramatic surge of interest in neuroimaging studies of working memory, two general science magazines (*Science* and *Scientific American*) recently published articles that report the state of the art of research inquiry into the neural basis of working memory (Beardsley, 1997; Wickelgren, 1997). Working memory research has also made important advances on the theoretical front, producing a number of well-developed models of working memory that are quite diverse in their theoretical scope and emphasis (e.g., Anderson, Reder, & Lebiere, 1996; Baddeley, 1986; Barnard, 1985; Cowan, 1988; Ericsson & Kintsch, 1995; Just & Carpenter, 1992; Schneider & Detweiler, 1987).

We believe that the field has made significant progress during the past 25 years and has reached a critical point at which detailed comparisons of different theoretical proposals are not only possible but would be tremendously beneficial for further theoretical development of working memory research. The central rationale behind this volume is to provide such a forum for systematic comparisons of existing models and theories of working memory.

This strong theoretical focus reflects a current need in the field. Whereas existing models of working memory each provide a sophisticated account of certain aspects of working memory processes and functions, different models have different theoretical emphases and tend to leave some other aspects of working memory relatively unspecified. Although such differences in scope and emphasis are quite natural and not necessarily bad, they could have some

negative consequences on working memory research by serving as a source of misunderstanding and confusion and making detailed empirical and theoretical evaluations of different theoretical proposals a rather difficult task.

The main goal of this volume is to alleviate this problem and encourage communication among different working memory researchers by focusing on detailed comparisons of current working memory models. This volume attempts to fulfill this goal by asking leading working memory theorists in the field to address the same set of theoretical issues and questions that have been guiding recent research in this area. These designated questions, to be explained and motivated in Chapter 1 (see Table 1.1), are broad in scope and concern the nature, functions, and structure of working memory as well as its biological implementation. By explicitly asking each contributor to address a common set of important (and often controversial) issues and questions, we thought we might be able to better elucidate the commonalities and differences among different working memory models that may not necessarily have been clear and/or may not have been fully appreciated before.

It is probably important to point out here our bias in the selection of the working memory models represented in this volume. Our main focus was to include models or theoretical frameworks that are broad enough in their scope that they can provide principled answers to the designated questions. We believe that working memory is not an isolated cognitive component that operates independently of other aspects of cognition and, hence, that a complete understanding of working memory requires considering it within a broader context of a cognitive architecture. The models included in this volume, thus, are often more than just models of working memory and have a lot to say about the overall architecture of human cognition.

This emphasis on the breadth of theoretical scope means that some important models or theoretical approaches that focus primarily on some specific aspects of working memory are not included in this volume. For example, we decided not to include a number of well-developed computational models of phonological short-term memory documented in the literature, primarily because these computational models cannot provide a basis for many (if not all) of the wide-ranging designated questions, although they are impressive in their details and precision. We refer readers interested in these models to the Gathercole (1996) volume. For a similar reason, we were also not able to represent in this volume interesting conceptions and theoretical proposals that are derived primarily from empirical research on one specific aspect of working memory, such as the nature of working memory involved in sentence comprehension and the neural/cellular basis of object and spatial working memory.

Even though we focus on models and theoretical frameworks with a broader scope, we probably have missed some important models of working memory. One such model is Just and Carpenter's, originally outlined in their 1992 article. They were invited to contribute a chapter to this volume, but, unfortunately, they decided not to contribute a chapter partly because of pre-

vious commitments and partly because of considerable changes in their views since 1992 as a result of their recent work on functional neuroimaging.

Despite these provisos, we believe that this volume nonetheless represents a wide range of influential theoretical perspectives on working memory and that the contributors have done an excellent job of fleshing out their current theoretical views. As editors, however, we attempted to make sure that this book is more than simply a collection of excellent chapters describing different theoretical perspectives. The editing process implemented a number of mechanisms that would ensure that the 13 chapters are tightly integrated with one another in such a way that readers will have a good idea of how these models of working memory are related to one another.

First, as we mentioned, the chapters in this volume addressed the same set of theoretical questions, which not only serve as recurring themes that run through the entire volume, but also provide a basis for systematic comparisons across different models of working memory represented in this volume (Chapters 2 to 11). Although the contributors differ in the way they addressed the eight designated questions (some directly tackle them one by one, whereas others address them within the context of describing their own model and relevant empirical research), they nonetheless addressed all the questions in some way or other. These designated questions are also the main focus of the remaining three chapters in this volume. The introductory chapter (Chapter 1) outlines the eight designated theoretical questions and their significance in working memory research. The discussion chapter (Chapter 12) revisits the designated questions one by one, compares and contrasts the answers provided by each chapter, and evaluates how well the models as a whole addressed each theoretical issue. Finally, the concluding chapter (Chapter 13) points out some commonalities that seem to be emerging across the 10 models and lists some of the unresolved theoretical issues for each of the designated questions.

Second, the editing process provided ample opportunities for the contributors to exchange their opinions and relate their own perspectives to other theorists' perspectives. After the first drafts of the chapters were in, all the contributors got together at the University of Colorado, Boulder, campus for a four-day companion symposium entitled "Models of Working Memory" (July 10–13, 1997) to present the ideas developed in their respective chapters, exchange their viewpoints, and comment on each other's answers to the eight designated questions. We believe this volume is all the better for the active interactions we had at the symposium. The symposium was particularly informative in making us realize that, although there are certainly some differences in opinion, these seemingly different models of working memory indeed have a lot in common. Thus, the ensuing revision process (each chapter was revised at least twice) was designed to make sure that this volume, as a whole, reflects this sense of emerging unity across different models. Specifically, we asked each chapter author to briefly refer to other models in this volume whenever they

express similar (and sometimes contrasting) ideas or viewpoints. To facilitate this cross-referencing process, we made the drafts of different chapters available on a protected web site so that the contributors could refresh their memory about the theoretical claims of other models and also check the accuracy of their cross-references. As a result, the chapters in this volume include extensive, insightful cross-references to other chapters, which we believe give readers a good sense of how different models relate to one another even before they read the final integrative chapters (Chapters 12 and 13).

Third, we also incorporated a number of features that we believe might help readers understand and remember the theoretical positions of different models and, possibly, do their own in-depth comparisons of the models in this volume. For example, each chapter that describes a specific model of working memory (Chapters 2 to 11) starts with a brief abstract that points out the five central features of that model. Also, each theory chapter contains a table that concisely summarizes the model's answers to each of the eight designated theoretical questions. We believe that this "Five Central Features of the Theory" abstract and the summary table in each chapter together provide a good overview of what that model is like. These features also serve as a useful memory aid – we ourselves went back to these summary tables many times to refresh our memories when we were in the process of preparing and editing Chapters 1, 12, and 13. Moreover, the subject index was specifically designed to facilitate the comparison and evaluation of each chapter's answers to the eight designated questions.

Finally, we tried to make this volume as accessible as possible to student readers by soliciting reviews of chapter drafts from graduate students as well as active working memory researchers who did not contribute to this volume. Specifically, we gave drafts of the chapters to several graduate students in cognitive psychology or cognitive neuroscience who were not particularly familiar with the models described in the assigned chapters and asked them to identify the sections that were not clear and needed further explanation. We believe that these comments from student reviewers as well as expert reviewers helped make the complex theoretical ideas and proposals accessible to readers of this volume.

Although neither of us had any prior experience in editing a book, we are quite pleased with the final product. It is our hope that this volume will serve not only as a milestone that documents recent theoretical progress in working memory research but also as a thought-provoking guidebook that could trigger whole new lines of active research projects and more precise and comprehensive models of working memory.

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Ode on Working Memory

There once was a box called short-term store
Whose function was storage and nothing more.
But along came Alan Baddeley
Whose subjects dual-tasked madly
And WM replaced STS forevermore.

For those who've been living in caves
Working memory is a system with slaves.
They are independent buffers
So that neither one suffers
When doing verbal memory with visual maze.

While storage is the job of each little slave
The central executive says how we behave.
From up in the prefrontal lobes
It activates and controls all nodes
Through a dopamine system acting as gates.

The unanswered questions on WM abound
Despite numerous studies whose findings are sound.
What's needed right now
Is for us to see how
We can put all these data on common ground.

JANICE KEENAN

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