

## The Cambridge Handbook of Visuospatial Thinking

The ability to navigate across town, comprehend an animated display of the functioning of the human heart, view complex multivariate data on a company's website, or read an architectural blueprint and form a three-dimensional mental picture of a house are all tasks involving visuospatial thinking. The field of visuospatial thinking is a relatively diverse interdisciplinary research enterprise. An understanding of visuospatial thinking, and in particular, how people represent and process visual and spatial information, is relevant not only to cognitive psychology but also to education, geography, architecture, medicine, design, computer science/artificial intelligence, semiotics, and animal cognition. The goal of this book is to present a broad overview of research on visuospatial thinking that can be used by researchers as well as students interested in this topic in both basic research and applied/naturalistic contexts.

Priti Shah is Assistant Professor in the Department of Psychology at the University of Michigan, Ann Arbor. She has published in the areas of spatial thinking, graphical display comprehension, and working memory, in such journals as the *Journal of Experimental Psychology: General*, the *Journal of Experimental Psychology: Applied*, the *Journal of Educational Psychology*, and *Science Education*.

Akira Miyake is Associate Professor in the Department of Psychology at the University of Colorado, Boulder. He is a Fellow of both American Psychological Association (Division 3: Experimental Psychology) and American Psychological Society. He has published in the areas of working memory, executive functions, language comprehension, and spatial thinking in such journals as *Cognitive Psychology* and the *Journal of Memory and Language*, and has been serving as Associate Editor for the *Journal of Experimental Psychology: General*.

Akira Miyake and Priti Shah are co-editors of another Cambridge University Press book (published in 1999), *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control*.

Cambridge University Press  
0521001730 - The Cambridge Handbook of Visuospatial Thinking  
Edited by Priti Shah and Akira Miyake  
Frontmatter  
[More information](#)

---

# The Cambridge Handbook of Visuospatial Thinking

Edited by  
**PRITI SHAH & AKIRA MIYAKE**



Cambridge University Press  
 0521001730 - The Cambridge Handbook of Visuospatial Thinking  
 Edited by Priti Shah and Akira Miyake  
 Frontmatter  
[More information](#)

CAMBRIDGE UNIVERSITY PRESS  
 Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo

Cambridge University Press  
 40 West 20th Street, New York, NY 10011-4211, USA

www.cambridge.org  
 Information on this title: www.cambridge.org/9780521807104

© Cambridge University Press 2005

This book is in copyright. Subject to statutory exception and to the provisions of relevant collective licensing agreements, no reproduction of any part may take place without the written permission of Cambridge University Press.

First published 2005

Printed in the United States of America

*A catalog record for this publication is available from the British Library.*

*Library of Congress Cataloging in Publication Data*

The Cambridge handbook of visuospatial thinking / edited by Priti Shah, Akira Miyake.

p. cm.

Includes bibliographical references and indexes.

ISBN 0-521-80710-7 (hardback) – ISBN 0-521-00173-0 (pbk.)

1. Mental representation. 2. Space perception. 3. Imagery (Psychology) 4. Visualization. 5. Thought and thinking.

I. Shah, Priti, 1968– II. Miyake, Akira, 1966– III. Title.

BF316.6.C36 2005

152.14'2 – dc22

2004020365

ISBN-13 978-0-521-80710-4 hardback

ISBN-10 0-521-80710-7 hardback

ISBN-13 978-0-521-00173-1 paperback

ISBN-10 0-521-00173-0 paperback

Cambridge University Press has no responsibility for the persistence or accuracy of URLs for external or third-party Internet Web sites referred to in this book and does not guarantee that any content on such Web sites is, or will remain, accurate or appropriate.

## Contents

<i>List of Contributors</i>	page vii
<i>Preface</i>	xi
<i>Acknowledgments</i>	xvii
1. Functional Significance of Visuospatial Representations <i>Barbara Tversky</i>	1
2. Visuospatial Images <i>Daniel Reisberg &amp; Friderike Heuer</i>	35
3. Disorders of Visuospatial Working Memory <i>Robert H. Logie &amp; Sergio Della Sala</i>	81
4. Individual Differences in Spatial Abilities <i>Mary Hegarty &amp; David A. Waller</i>	121
5. Sex Differences in Visuospatial Abilities: More Than Meets the Eye <i>Diane F. Halpern &amp; Marcia L. Collaer</i>	170
6. Development of Spatial Competence <i>Nora S. Newcombe &amp; Amy E. Learmonth</i>	213
7. Navigation <i>Daniel R. Montello</i>	257
8. Mapping the Understanding of Understanding Maps <i>Holly A. Taylor</i>	295
9. Spatial Situation Models <i>Mike Rinck</i>	334

10. Design Applications of Visual Spatial Thinking: The Importance of Frame of Reference <i>Christopher D. Wickens, Michelle Vincow, &amp; Michelle Yeh</i>	383
11. The Comprehension of Quantitative Information in Graphical Displays <i>Priti Shah, Eric G. Freedman, &amp; Ioanna Vekiri</i>	426
12. Multimedia Learning: Guiding Visuospatial Thinking with Instructional Animation <i>Richard E. Mayer</i>	477
<i>Author Index</i>	509
<i>Subject Index</i>	531

## List of Contributors

**Marcia L. Collaer**

Department of Psychology  
Middlebury College  
Middlebury, VT 05753  
collaer@middlebury.edu

**Sergio Della Sala**

Department of Psychology, PPLS  
University of Edinburgh  
Edinburgh EH89JZ  
Scotland, United Kingdom  
sergio@staffmail.ed.ac.uk

**Eric G. Freedman**

Department of Psychology  
University of Michigan, Flint  
Flint, MI 48502-1950  
freedman@umich.edu

**Diane F. Halpern**

Berger Institute for Work, Family,  
and Children  
Claremont McKenna College  
850 Columbia Ave.  
Claremont, CA 91711-6400  
Diane.Halpern  
@claremontmckenna.edu

**Mary Hegarty**

Department of Psychology  
University of California, Santa  
Barbara  
Santa Barbara, CA 93106  
hegarty@psych.ucsb.edu

**Friderike Heuer**

Department of Psychology  
Lewis & Clark College  
615 SW Palatine Hill Rd.  
Portland, OR 97219-7899  
heuer@lclark.edu

**Amy E. Learmonth**

Department of Psychology  
Rutgers University  
152 Frelinghuysen Rd.  
Piscataway, NJ 08854-8020  
amyel@rci.rutgers.edu

**Robert H. Logie**

Department of Psychology, PPLS  
University of Edinburgh  
Edinburgh EH89JZ  
Scotland, United Kingdom  
rlogie@staffmail.ed.ac.uk

**Richard E. Mayer**

Department of Psychology  
 University of California, Santa  
 Barbara  
 Santa Barbara, CA 93106  
 mayer@psych.ucsb.edu

**Akira Miyake**

Department of Psychology  
 University of Colorado at Boulder  
 345 UCB  
 Boulder, CO 80309-0345  
 akira.miyake@colorado.edu

**Daniel R. Montello**

Department of Geography  
 University of California, Santa  
 Barbara  
 Santa Barbara, CA 93106  
 montello@geog.ucsb.edu

**Nora S. Newcombe**

Department of Psychology  
 Temple University  
 Philadelphia, PA 19122  
 newcombe@astro.ocis.temple.edu

**Daniel Reisberg**

Department of Psychology  
 Reed College  
 3203 SE Woodstock Blvd.  
 Portland, OR 97202  
 Daniel.Reisberg  
 @directory.reed.edu

**Mike Rinck**

Maastricht University  
 Department of Medical, Clinical,  
 and Experimental Psychology  
 Postbus 616  
 6200 MD Maastricht, NL  
 M.Rinck@DMKEP.unimaas.nl

**Priti Shah**

Department of Psychology  
 525 East University  
 University of Michigan  
 Ann Arbor, MI 48109-1109  
 priti@umich.edu

**Holly A. Taylor**

Department of Psychology  
 Paige Hall  
 Tufts University  
 Medford, MA 02155  
 htaylor@tufts.edu

**Barbara Tversky**

Department of Psychology  
 Building 420  
 Jordan Hall  
 Stanford, CA 94305-2130  
 bt@psych.stanford.edu

**Ioanna Vekiri**

N. Plastira 103  
 Thessaloniki, 55132, Greece  
 aretsou@hol.gr

**Michelle Vincow**

Verizon Laboratories  
 18 Day St. #207  
 Somerville, MA 02144  
 mvincow@yahoo.com

**David A. Waller**

Department of Psychology  
 234 Benton Hall  
 Miami University  
 Oxford, OH 45056  
 wallerda@muohio.edu

Cambridge University Press  
0521001730 - The Cambridge Handbook of Visuospatial Thinking  
Edited by Priti Shah and Akira Miyake  
Frontmatter  
[More information](#)

---

*List of Contributors*

ix

**Christopher D. Wickens**

Beckman Institute  
University of Illinois  
405 N. Mathews  
Urbana, IL 61801  
cwickens@uiuc.edu

**Michelle Yeh**

Volpe National Transportation  
Systems Center  
55 Broadway  
Cambridge, MA 02142  
yeh@volpe.dot.gov



## Preface

Navigating across town, comprehending an animated display of the functioning of the human heart, viewing complex multivariate data on a business's website, reading an architectural blueprint, and forming a three-dimensional mental picture of a house are all tasks involving visuospatial thinking. As suggested by the breadth of this list of tasks, the field of visuospatial thinking is a relatively diverse interdisciplinary research enterprise. An understanding of visuospatial thinking – in particular, how people represent and process visual and spatial information – is relevant not only to the field of cognitive psychology but also to education, geography, architecture, medicine, design, computer science/artificial intelligence, semiotics, and animal cognition.

The goal of this handbook is to present a broad overview of the research on this topic that can be used by researchers interested in visuospatial thinking in both basic and applied or naturalistic contexts. The focus of this volume is higher-level visuospatial thinking, which involves the use of internal or external visual or spatial representations from visual imagery to diagrammatic reasoning. Our focus on higher-level visuospatial thinking contrasts with lower-level visuospatial cognition, such as object recognition, visual attention, and scene perception.

There are at least three reasons why we felt that there is a need for this handbook. First, historically, research on visuospatial thinking has been a relatively loosely connected enterprise, often with little interaction among researchers addressing related questions. For example, although there are similar issues involved in the processing of graphs, diagrams, and maps, little communication across these research areas exists, and few generic models or theories can provide a unified framework for the comprehension of various visual displays. Similarly, although research on visuospatial

thinking at multiple levels (e.g., object recognition, scene perception, diagram comprehension) has been done, few models cut across these levels. This state of affairs in the visuospatial thinking domain is in stark contrast to the field of text comprehension, where a number of well-developed models that cut across different levels of analysis already exist. By bringing together different lines of related research in a single volume, we believe that this handbook will provide one step toward the development of a more unified subdiscipline of cognitive science, the field of higher-level visuospatial thinking.

Another closely related reason is that much research on visuospatial thinking is distributed across different disciplines and in many cases has been conducted in the context of applied problems. For example, cognitive psychologists examine the nature of limitations in visuospatial working memory and specify the nature of individual and group differences in visuospatial abilities in lab-based settings (e.g., Logie & Della Sala, Chapter 3; Hegarty & Waller, Chapter 4; Halpern & Collaer, Chapter 5). At the same time, similar questions are asked in more applied contexts. Medical researchers consider how limitations in spatial abilities may affect surgeons using virtual tools, and meteorologists consider how spatial abilities may influence the interpretation of interactive weather displays. In another example, the communication of three-dimensional information in two-dimensional format is critical for many situations (e.g., Wickens, Vincow, & Yeh, Chapter 10; Shah, Freedman, & Vekiri, Chapter 11; and Mayer, Chapter 12), but extensive research related to this topic has been conducted in rather disparate fields, including chemistry, architecture, multimedia instruction, and radiology. Because of the distributed nature of research on visuospatial thinking across different domains, it has been difficult for researchers to know what relevant work has been done on a certain topic and to keep up with the large body of available research. A researcher in an applied domain (e.g., someone interested in three-dimensional visuospatial thinking during surgery) may not be prepared to identify the different communities that have examined related questions. Our intention is to bring together the important research on visuospatial thinking in different contexts so that researchers in various disciplines can apply what has been learned in other subfields of visuospatial thinking to their own fields.

A third reason for editing a handbook on visuospatial thinking is that current technology requires new types of visuospatial thinking. Information technology, for example, requires people to comprehend and use animated, three-dimensional, and interactive displays and also to navigate through virtual as well as physical space. Along with such technological

advances are numerous new empirical studies – yet again, these studies are frequently done within the context of specific fields without making much contact with related research in other disciplines. In this handbook, several examples of visuospatial thinking involving current technology from navigation through virtual space to the comprehension of complex multimedia representations are presented and discussed in some detail.

We decided against including a larger number of short chapters, as is frequently done in books with the word *handbook* in the title. We instead opted for providing in-depth reviews of central topics in higher-level visuospatial thinking so that readers may gain a strong foundation in each selected topic. This means that the information contained here does not cover all possible topics within research on visuospatial thinking, but many of the core topics are covered in a fairly comprehensive manner in each chapter. From our own experience, we have found handbooks that are somewhat selective but offer an in-depth coverage of major topics more useful than those that offer a comprehensive yet somewhat cursory treatment of many topics, and we hope that readers also see some benefits in our “selective, in-depth” approach.

The handbook can be loosely divided into four sections, beginning with a section with the basic cognitive mechanisms underlying visuospatial thought, such as visuospatial imagery and working memory. In Chapter 1, Barbara Tversky begins with a fundamental theoretical issue that applies to all the remaining chapters in the volume, the role of visuospatial representations in human thought. Specifically, in her tutorial overview chapter, she addresses such fundamental questions as, “What kinds of internal and external visuospatial representations do we use, how do they relate to one another, and for what are they useful?” In Chapter 2, Dan Reisberg and Friderike Heuer provide an up-to-date review of research on mental imagery. Their chapter also includes the latest research on the neural basis of mental imagery, including sections on neuroimaging studies and research on neuropsychological patients with mental imagery deficits. In Chapter 3, Robert Logie and Sergio Della Sala provide an in-depth discussion of one important building block of visuospatial thinking – visuospatial working memory – from the perspective of neuropsychological studies of disorders of visuospatial cognition, particularly those of hemispatial neglect.

The second section of the handbook focuses on individual and group differences in spatial abilities. We devote a few chapters to this topic because historically this topic has been a relatively large component of cognitive research on visuospatial thinking and has been of practical importance to most applied topics in visuospatial thinking. In Chapter 4, Mary Hegarty

and David Waller review the research on individual differences in visuospatial thinking, including psychometric spatial abilities, navigational skill, mechanical reasoning abilities, and other visuospatial abilities. They also consider various relationships among spatial abilities (e.g., navigation skill and psychometric spatial skill), the relationship between spatial ability and other skills (e.g., mathematical ability and musical skills), and the effects of aging on visuospatial thinking. In Chapter 5, Diane Halpern and Marcia Collaer critically evaluate evidence for sex-related differences in visuospatial abilities in humans and other animals. In addition, they consider underlying explanations for sex-related differences, such as differences in brain laterality, hormones, and life experiences. Finally, in Chapter 6, Nora Newcombe and Amy Learmonth provide an in-depth, theoretically motivated account of the development of spatial skills. The authors' main focus is children's ability to represent and use knowledge about geographical space, such as their ability to remember spatial locations, imagine space from different perspectives, and navigate through space.

The third section of the handbook focuses on constructing and using visuospatial mental representations in the performance of complex everyday tasks, such as navigation, map reading, and the comprehension of verbal directions. In Chapter 7, Daniel Montello provides a comprehensive review of current views on the mechanisms and representations involved in human navigation. In Chapter 8, Holly Taylor discusses research on the comprehension and production of maps and other external representations of geographical space. Finally, Chapter 9, written by Mike Rinck, concerns the nature of processes and representations involved in the mental construction of spatial representations from verbal descriptions (e.g., reading a passage in which the main character moves from one location to another). Called *spatial situation models*, these representations serve as an interface between visuospatial thinking and language comprehension.

The final section of the handbook presents four exemplar applied contexts that have lately received a large amount of research attention. In Chapter 10, Chris Wickens, Michelle Vincow, and Michelle Yeh discuss two of these contexts: navigational displays (e.g., pilot navigation or head mounted displays) and information visualization displays. In their chapter, the authors emphasize the importance of various frames of reference and the difficulties of translating between frames of reference in the context of different tasks. In Chapter 11, Priti Shah, Eric Freedman, and Ioanna Vekiri describe research on the comprehension of graphs. They consider the display, content, task, and individual difference factors that influence the interpretation of quantitative data presented visually. Finally, in Chapter 12,

Richard Mayer examines the effects of visuospatial media on thinking and learning from an educational perspective and presents a model of multimedia comprehension and principles of multimedia.

As mentioned, this handbook is intended to serve as a resource for readers in the cognitive sciences as well as researchers in related disciplines who may have an applied interest in visuospatial cognition. In addition, we hope that this volume will be useful to advanced undergraduate and graduate students and other individuals who are interested in learning about the field of visuospatial thinking but do not have strong background knowledge in it.

To make this volume accessible to a broad, interdisciplinary audience as well as to novice student readers, we have implemented a number of features.

We asked chapter authors to define the technical terms that they used in their chapters, even when those terms were used in other chapters, so that each chapter can serve as an independent resource for the reader. Also, because handbook readers usually read a subset of chapters relevant to their interests rather than reading the entire book from cover to cover, we have deliberately maintained some level of redundancy across chapters so that readers would not have to refer to other chapters to comprehend the one they are reading. At the same time, we have included a number of cross-references in each chapter so that interested readers can learn more about the related topics by taking a look at other related chapters. Additionally, we solicited reviews of chapter drafts from graduate students. We explicitly asked these reviewers to identify any concepts or technical terms that were unclear to the reader and then asked the authors to revise their chapters accordingly. Each chapter was reviewed by experts in certain aspects of visuospatial thinking research so that the contents of each chapter are accurate and of interest to expert researchers in the field as well. Finally, we asked authors to provide a list of important further readings so that readers can use these chapters as a springboard for learning about different subfields of visuospatial thinking.

The field of visuospatial thinking is a diverse interdisciplinary research community. We hope that this handbook serves as a useful resource for researchers currently conducting research in visuospatial thinking as well as researchers new to the field and that it also provides a useful bridge between basic and applied research on visuospatial thinking.

Priti Shah and Akira Miyake

## Acknowledgments

We would like to thank a number of people and agencies that have supported this book project.

First, we would like to acknowledge granting agencies that have supported our own work during the time we have been working on this book. Priti Shah was supported by grants from the Office of Naval Research (N00014-98-1-0812, N00014-98-1-0350, and N00014-02-1-0279). Akira Miyake was supported by grants from the National Institute of Mental Health (MH63207).

We owe a debt of gratitude to the two groups of reviewers who provided detailed feedback on the chapters contained in this handbook. One group of reviewers consisted of experts on certain aspects of visuospatial thinking. The other group of reviewers were graduate students. For each chapter, two graduate students, one from within the discipline of cognitive psychology and one from outside of cognitive psychology but in a field relevant to visuospatial cognition (e.g., education, information science), reviewed the chapters for readability, comprehensibility, and content. These reviewers were (in alphabetical order): Damian Betebenner, Kirsten Butcher, Leslie Cohen, David Collister, Elizabeth Davis, Patricia DeLucia, Mike Emerson, Naomi Friedman, Julie Heiser, Jeff Holmes, Alex Kauper, Steve Kosslyn, Kate Masarik, Joe Mikels, Beth Mulligan, Mitch Nathan, Naomi Norman, Danny Oppenheimer, David Pearson, Jim Pellegrino, John Reiser, Patricia Reuter-Lorenz, Matt Rossano, Gunnar Schrah, Julia Sluzenski, Jim Van Overschelde, Sashank Varma, Daniel Voyer, and Rolf Zwaan. Thanks to all.

We would also like to thank people who generously helped us at various stages of the book project, including Linda Anderson, Aysecan Boduroglu, Evelyn Craft-Robinson, and Rachel Orłowski at the University of Michigan

and Michie Shaw and Andrew Wilson at TechBooks. We would particularly like to thank our editor at Cambridge University Press, Phil Laughlin, for his thorough and timely help and especially his patience.

In addition, Priti Shah gratefully acknowledges the support of her colleagues and students at the University of Michigan on this book project as well as on her research. Jim Hoeffner has provided much love and support during the entire editing process. He deserves a mountain of thanks (and a vacation) (or two). Finally, Kiran and Avani provided lots of joyful diversions.

Akira Miyake gratefully acknowledges the support of his colleagues at the University of Colorado, Boulder, where most of the editing of this handbook (as well as our previous book with Cambridge University Press, *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control*) took place. He is extremely grateful for the encouragement that his Boulder colleagues, students, and friends provided on these book projects as well as his research. He would also like to thank the University of Toronto for providing necessary resources for completing the last stages of the handbook editing process.