Cognitive Neuroscience of Memory

Within the last two decades, the field of cognitive neuroscience has begun to thrive with technological advances that non-invasively measure human brain activity. This is the first book to provide a comprehensive and up-to-date treatment on the cognitive neuroscience of memory. Topics include cognitive neuroscience techniques and human brain mechanisms underlying long-term memory success, long-term memory failure, working memory, implicit memory, and memory and disease. Cognitive Neuroscience of Memory highlights both spatial and temporal aspects of the functioning human brain during memory. Each chapter is written in an accessible style and includes background information and many figures. In his analysis, Scott Slotnick questions popular views, rather than simply assuming they are correct. In this way, science is depicted as open to question, evolving, and exciting.

Scott D. Slotnick is an Associate Professor of Psychology at Boston College, Editor-in-Chief of the journal Cognitive Neuroscience, and author of the book Controversies in Cognitive Neuroscience. He employs multiple cognitive neuroscience techniques to investigate the brain mechanisms underlying memory including functional magnetic resonance imaging (fMRI), electroencephalography (EEG), and transcranial magnetic stimulation (TMS).
Cambridge Fundamentals of Neuroscience in Psychology

Developed in response to a growing need to make neuroscience accessible to students and other non-specialist readers, the Cambridge Fundamentals of Neuroscience in Psychology series provides brief introductions to key areas of neuroscience research across major domains of psychology. Written by experts in cognitive, social, affective, developmental, clinical, and applied neuroscience, these books will serve as ideal primers for students and other readers seeking an entry point to the challenging world of neuroscience.

Forthcoming Titles in the Series

The Neuroscience of Intelligence, by Richard J. Haier
The Neuroscience of Expertise, by Merim Bilalić
The Neuroscience of Adolescence, by Adriana Galván
The Neuroscience of Aging, by Angela Gutchess
The Neuroscience of Addiction, by Francesca Filbey
Cognitive Neuroscience of Memory

Scott D. Slotnick

Boston College
This book is dedicated to my incredible daughter Sonya, for dominating my hippocampal sharp-wave ripples these past twelve years.
As regards the question . . . what memory or remembering is . . . it is the state of a presentation, related as a likeness to that of which it is a presentation; and as to the question of which of the faculties within us memory is a function . . . it is a function of the primary faculty of sense-perception, i.e. of that faculty whereby we perceive time.

(Aristotle, [350 BCE] 1941, p. 611)
Contents

List of Figures
Preface

1 Types of Memory and Brain Regions of Interest 1
1.1 Cognitive Neuroscience 2
1.2 Memory Types 3
1.3 Brain Anatomy 8
1.4 The Hippocampus and Long-Term Memory 12
1.5 Sensory Regions 13
1.6 Control Regions 18
1.7 The Organization of This Book 21

2 The Tools of Cognitive Neuroscience 24
2.1 Behavioral Measures 25
2.2 High Spatial Resolution Techniques 25
2.3 High Temporal Resolution Techniques 30
2.4 High Spatial and Temporal Resolution Techniques 34
2.5 Lesions and Temporary Cortical Disruption Techniques 37
2.6 Method Comparisons 43

3 Brain Regions Associated with Long-Term Memory 46
3.1 Episodic Memory 47
3.2 Semantic Memory 51
3.3 Memory Consolidation 53
3.4 Consolidation and Sleep 56
3.5 Memory Encoding 59
3.6 Sex Differences 61
3.7 Superior Memory 64

4 Brain Timing Associated with Long-Term Memory 71
4.1 Timing of Activity 72
4.2 The FN400 Debate 76
4.3 Phase and Frequency of Activity 79
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Long-Term Memory Failure</td>
<td>88</td>
</tr>
<tr>
<td>5.1</td>
<td>Typical Forgetting</td>
<td>89</td>
</tr>
<tr>
<td>5.2</td>
<td>Retrieval-Induced Forgetting</td>
<td>92</td>
</tr>
<tr>
<td>5.3</td>
<td>Motivated Forgetting</td>
<td>96</td>
</tr>
<tr>
<td>5.4</td>
<td>False Memories</td>
<td>97</td>
</tr>
<tr>
<td>5.5</td>
<td>Flashbulb Memories</td>
<td>103</td>
</tr>
<tr>
<td>6</td>
<td>Working Memory</td>
<td>108</td>
</tr>
<tr>
<td>6.1</td>
<td>The Contents of Working Memory</td>
<td>109</td>
</tr>
<tr>
<td>6.2</td>
<td>Working Memory and the Hippocampus</td>
<td>114</td>
</tr>
<tr>
<td>6.3</td>
<td>Working Memory and Brain Frequencies</td>
<td>119</td>
</tr>
<tr>
<td>6.4</td>
<td>Brain Plasticity and Working Memory Training</td>
<td>122</td>
</tr>
<tr>
<td>7</td>
<td>Implicit Memory</td>
<td>129</td>
</tr>
<tr>
<td>7.1</td>
<td>Brain Regions Associated with Implicit Memory</td>
<td>130</td>
</tr>
<tr>
<td>7.2</td>
<td>Brain Timing Associated with Implicit Memory</td>
<td>135</td>
</tr>
<tr>
<td>7.3</td>
<td>Models of Implicit Memory</td>
<td>138</td>
</tr>
<tr>
<td>7.4</td>
<td>Implicit Memory and the Hippocampus</td>
<td>141</td>
</tr>
<tr>
<td>7.5</td>
<td>Skill Learning</td>
<td>146</td>
</tr>
<tr>
<td>8</td>
<td>Memory and Other Cognitive Processes</td>
<td>150</td>
</tr>
<tr>
<td>8.1</td>
<td>Attention and Memory</td>
<td>151</td>
</tr>
<tr>
<td>8.2</td>
<td>Imagery and Memory</td>
<td>159</td>
</tr>
<tr>
<td>8.3</td>
<td>Language and Memory</td>
<td>164</td>
</tr>
<tr>
<td>8.4</td>
<td>Emotion and Memory</td>
<td>166</td>
</tr>
<tr>
<td>9</td>
<td>Explicit Memory and Disease</td>
<td>171</td>
</tr>
<tr>
<td>9.1</td>
<td>Amnestic Mild Cognitive Impairment</td>
<td>172</td>
</tr>
<tr>
<td>9.2</td>
<td>Alzheimer’s Disease</td>
<td>177</td>
</tr>
<tr>
<td>9.3</td>
<td>Mild Traumatic Brain Injury</td>
<td>179</td>
</tr>
<tr>
<td>9.4</td>
<td>Medial Temporal Lobe Epilepsy</td>
<td>186</td>
</tr>
<tr>
<td>9.5</td>
<td>Transient Global Amnesia</td>
<td>190</td>
</tr>
<tr>
<td>10</td>
<td>Long-Term Memory in Animals</td>
<td>196</td>
</tr>
<tr>
<td>10.1</td>
<td>The Medial Temporal Lobe</td>
<td>197</td>
</tr>
<tr>
<td>10.2</td>
<td>Long-Term Potentiation</td>
<td>200</td>
</tr>
<tr>
<td>10.3</td>
<td>Memory Replay</td>
<td>203</td>
</tr>
<tr>
<td>10.4</td>
<td>Time Cells</td>
<td>205</td>
</tr>
<tr>
<td>10.5</td>
<td>Episodic Memory</td>
<td>210</td>
</tr>
</tbody>
</table>
Contents

11 The Future of Memory Research 219
  11.1 Phrenology and fMRI 220
  11.2 fMRI versus ERPs 225
  11.3 Brain Region Interactions 227
  11.4 The Future of Cognitive Neuroscience 232
  11.5 A Spotlight on the Fourth Dimension 234

Glossary 238
References 248
Author Index 270
Subject Index 276

Color plates are to be found between pp. 170 and 171
Figures

1.1 The relationships between the fields of cognitive psychology, cognitive neuroscience, and behavioral neuroscience.  

1.2 Organization of memory types.

1.3 Probability of “remember” or “know” responses as a function of confidence judgments.

1.4 Brain regions associated with memory.

1.5 Gyri and sulci in brain regions of interest.

1.6 Brodmann map.

1.7 Depiction of medial temporal lobe resection in patient H. M. Reproduced from Journal of Neurology, Neurosurgery, & Psychiatry, Loss of recent memory after bilateral hippocampal lesions, William Beecher Scoville and Brenda Milner, Volume 20, Pages 11–21, Copyright (1957), with permission from BMJ Publishing Group Ltd.

1.8 Sensory brain regions of interest.

1.9 Sensory fMRI activity associated with perception and memory.

1.10 Item memory and source memory paradigm and fMRI results. Reprinted from Cognitive Brain Research, Volume 17, Scott D. Slotnick, Lauren R. Moo, Jessica B. Segal, and John Hart, Jr., Distinct prefrontal cortex activity associated with item memory and source memory for visual shapes, Pages 75–82, Copyright (2003), with permission from Elsevier.

2.1 MRI scanner and fMRI results. (A) Photo courtesy of Preston Thakral. (B, C) Reprinted from Proceedings of the National Academy of Sciences of the United States of America, Volume 93, Randy L. Buckner, Peter A. Bandettini, Kathleen M. O’Craven, Robert L. Savoy, Steven E. Petersen, Marcus E. Raichle, and Bruce R. Rosen, Detection of cortical activation during averaged single trials of a cognitive task using functional magnetic resonance imaging, Pages 14878–14883, Copyright (1996) National Academy of Sciences, USA.

2.2 ERP setup and results. (A) Photo courtesy of Scott Slotnick. Reprinted from NeuroImage, Volume 39, Jeffrey D. Johnson, Brian R. Minton, and Michael D. Rugg, Content dependence...
List of Figures xi

of the electrophysiological correlates of recollection, Pages 406–416, Copyright (2008), with permission from Elsevier. 31

2.3 MEG setup. Photo courtesy of CTFMEG/MEG International Services Ltd., Canada. 33


2.5 Hippocampal lesion and recognition memory results. Reprinted from Neuron, Volume 37, Joseph R. Manns, Ramona O. Hopkins, Jonathan M. Reed, Erin G. Kitchener, and Larry R. Squire, Recognition memory and the human hippocampus, Pages 171–180, Copyright (2003), with permission from Elsevier. 38

2.6 TMS setup and fMRI guided TMS results. (A, B) Photos courtesy of Scott Slotnick. Reprinted from NeuroImage, Volume 55, Scott D. Slotnick and Preston P. Thakral, Memory for motion and spatial location is mediated by contralateral and ipsilateral motion processing cortex, Pages 794–800, Copyright (2011), with permission from Elsevier. 40

2.7 tDCS setup. Photo courtesy of Bryan Coppede. 42

2.8 Spatial resolution and temporal resolution for different methods. 43

3.1 Regions of the brain associated with episodic memory. Reprinted from Current Opinion in Neurobiology, Volume 23(2), Michael D. Rugg and Kaia L. Vilberg, Brain networks underlying episodic memory retrieval, Pages 255–260, Copyright (2013), with permission from Elsevier. 48

3.2 Model of medial temporal lobe sub-region function. Reprinted from NeuroReport, Volume 24(12), Scott D. Slotnick, The nature of recollection in behavior and the brain, Pages 663–670, Copyright (2013), with permission from Wolters Kluwer. 49

3.3 Regions of the brain associated with semantic memory. Reprinted from NeuroImage, Volume 63(1), Kimiko Domoto-Reilly, Daisy Sapolsky, Michael Brickhouse, and Bradford C. Dickerson,
Naming Impairment in Alzheimer’s disease is associated with left anterior temporal lobe atrophy, Pages 348–355, Copyright (2012), with permission from Elsevier.

3.4 Autobiographical memory disruption for recent and remote events in patients with hippocampal lesions. Reprinted from *Proceedings of the National Academy of Sciences of the United States of America*, Volume 108, Thorsten Bartsch, Juliane Döhring, Axel Rohr, Olav Jansen, and Günther Deuschl, CA1 neurons in the human hippocampus are critical for autobiographical memory, mental time travel, and autonoetic consciousness, Pages 17562–17567, Copyright (2011) National Academy of Sciences, USA.

3.5 Sleep stages and brain oscillations associated with slow wave sleep and long-term memory consolidation. (A) Reprinted from *Trends in Neurosciences*, Volume 28(8), Robert Stickgold and Matthew P. Walker, Memory consolidation and reconsolidation: What is the role of sleep, Pages 408–415, Copyright (2005), with permission from Elsevier. (B) Reprinted from *Psychological Research*, Volume 76(2), Jan Born and Ines Wilhelm, System consolidation of memory during sleep, Pages 192–203, Copyright (2012), with permission from Springer.


3.8 Change in the size of the posterior hippocampus as a function of time as a London taxi driver. Reprinted from *Proceedings of the National Academy of Sciences of the United States of America*, Volume 97, Eleanor A. Maguire, David G. Gadian, Ingrid S. Johnsrude, Catriona D. Good, John Ashburner, Richard S. J. Frackowiak, and Christopher D. Frith,
List of Figures

Navigation-related structural change in the hippocampi of taxi drivers, Pages 4398–4403, Copyright (2000) National Academy of Sciences, USA.


4.3 Topographic maps illustrating the conceptual priming effect and the mid-frontal old–new effect. Reprinted from *NeuroImage*, Volume 63(3), Emma K. Bridger, Regine Bader, Olga Kriukova, Kerstin Unger, and Axel Mecklinger, The FN400 is functionally distinct from the N400, Pages 1334–1342, Copyright (2012), with permission from Elsevier.

4.4 Topographic maps and activation timecourses illustrating spatial memory effects. Reprinted from *Brain Research*, Volume 1330, Scott D. Slotnick, Synchronous retinotopic frontal-temporal activity during long-term memory for spatial location, Pages 89–100, Copyright (2010), with permission from Elsevier.

4.5 EEG frequency band activity associated with subsequently remembered and forgotten items. Reprinted from *NeuroImage*, Volume 66, Uwe Friese, Moritz Köster, Uwe Hassler, Ulla Martens, Nelson Trujillo-Barreto, and Thomas Gruber, Successful memory encoding is associated with increased cross-frequency coupling between frontal theta and posterior gamma oscillations in human scalp-recorded EEG, Pages 642–647, Copyright (2013), with permission from Elsevier.

List of Figures


5.4 Regions of the brain commonly and differentially associated with true memory and related false memory. Reprinted from *Nature Neuroscience*, Volume 7(6), Scott D. Slotnick and Daniel L. Schacter, A sensory signature that distinguishes true from false memories, Pages 664–672, Copyright (2004).

5.5 Brain activity associated with unrelated false memory. Rachel J. Garoff-Eaton, Scott D. Slotnick, and Daniel L. Schacter, Not all false memories are created equal: The neural basis of false recognition, *Cerebral Cortex*, 2006, 16(11), 1645–1652, by permission of Oxford University Press.

6.1 Object or location working memory paradigm and fMRI results. Reprinted from *Neuropsychologia*, Volume 41(3), Joseph B. Sala, Pia Rämä, and Susan M. Courtney, Functional topography of a distributed neural system for spatial and nonspatial information maintenance in working memory, Pages 341–356, Copyright (2003), with permission from Elsevier.

6.2 Sustained working memory fMRI activity in the dorsolateral prefrontal cortex. Reprinted from *Trends in Cognitive Sciences*, Volume 7(9), Clayton E. Curtis and Mark D’Esposito, Persistent activity in the prefrontal cortex during working memory, Pages 415–423, Copyright (2003), with permission from Elsevier.

6.3 Color and/or location working memory paradigms and medial temporal lobe lesion results. Reprinted from *Neuropsychologia*, Volume 46(2), Carsten Finke, Mischa Braun, Florian Ostendorf, Thomas-Nicolas Lehmann, Karl-
List of Figures

Titus Hof, Ute Kopp, and Christoph J. Ploner,
The human hippocampal formation mediates short-term memory of colour-location associations, Pages 614–623, Copyright (2008), with permission from Elsevier.


7.1 Repetition priming paradigm and fMRI results. Reprinted from *Neuropsychologia*, Volume 39(2), Wilma Koutstaal, Anthony D. Wagner, Michael Rotte, Anat Maril, Randy L. Buckner, and Daniel L. Schacter, Perceptual specificity in visual object priming: Functional magnetic resonance imaging evidence for a laterality difference in fusiform cortex, Pages 184–199, Copyright (2001), with permission from Elsevier.


7.4 Models of repetition priming. Reprinted from *Trends in Cognitive Sciences*, Volume 10(1), Kalanit Grill-Spector,
xvi

List of Figures

Richard Henson, and Alex Martin, Repetition and the brain: Neural models of stimulus-specific effects, Pages 14–23, Copyright (2006), with permission from Elsevier. 139

7.5 Contextual cuing stimulus display. 143

7.6 Skill learning behavioral results and fMRI results. Reprinted from Brain Research, Volume 1318, Liangsuo Ma, Binquan Wang, Shalini Narayana, Eliot Hazeltine, Xiying Chen, Donald A. Robin, Peter T. Fox, Jinhu Xiong. Changes in regional activity are accompanied with changes in inter-regional connectivity during 4 weeks motor learning, Pages 64–76, Copyright (2010), with permission from Elsevier. 146

8.1 Spatial attention paradigm and fMRI results. (B) Reprinted from Neuropsychologia, Volume 39(12), Joseph B. Hopfinger, Marty G. Woldorff, Evan M. Fletcher, and George R. Mangun, Dissociating top-down attentional control from selective perception and action, Pages 1277–1291, Copyright (2001), with permission from Elsevier. (C) Reprinted from Brain Research, Volume 1302, Preston P. Thakral and Scott D. Slotnick, The role of parietal cortex during sustained visual spatial attention, Pages 157–166, Copyright (2009), with permission from Elsevier. 153

8.2 Spatial memory fMRI and ERP results. Reprinted from Brain Research, Volume 1268, Scott D. Slotnick, Rapid retinotopic reactivation during spatial memory, Pages 97–111, Copyright (2009), with permission from Elsevier. 156


8.4 Visual perception, imagery, and attention paradigms and fMRI results. Scott D. Slotnick, William L. Thompson, and Stephen M. Kosslyn, Visual mental imagery induces retinotopically organized activation of early visual areas, Cerebral Cortex, 2005, 15(10), 1570–1583, by permission of Oxford University Press. 160

8.5 Language processing regions. Reprinted from Journal of Anatomy, Volume 197, Cathy J. Price, The anatomy of language: Contributions from functional neuroimaging, Pages xvi

© in this web service Cambridge University Press & Assessment www.cambridge.org
List of Figures xvii

335–359, Copyright (2000), with permission from
John Wiley & Sons, Inc. 164

8.6 The amygdala and the hippocampus. Reprinted from Current Opinion in Neurobiology, Volume 14(2), Elizabeth A. Phelps, Human emotion and memory: Interactions of the amygdala and hippocampal complex, Pages 198–202, Copyright (2004), with permission from Elsevier. 167


9.2 Pattern separation paradigm, behavioral results, and fMRI results for control participants and aMCI patients. Reprinted from NeuroImage, Volume 51(3), Michael A. Yassa, Shauna M. Stark, Arnold Bakker, Marilyn S. Albert, Michela Gallagher, and Craig E. L. Stark, High-resolution structural and functional MRI of hippocampal CA3 and dentate gyrus in patients with amnestic mild cognitive impairment, Pages 1242–1252, Copyright (2010), with permission from Elsevier. 175


9.4 N-back paradigm, behavioral results, and fMRI results for mild traumatic brain injury patients and control participants. Reprinted from NeuroImage, Volume 14(5), Thomas W. McAllister, Molly B. Sparling, Laura A. Flashman, Stephen J. Guerin, Alexander C. Mamourian, and Andrew J. Saykin, Differential working memory load effects after mild traumatic brain injury, Pages 1004–1012, Copyright (2001), with permission from Elsevier. 182
9.5 Stimuli and behavioral results for control participants and medial temporal lobe epilepsy patients following removal of left or right medial temporal lobe regions. Reprinted from *Neuropsychologia*, Volume 24(5), Marilyn Jones-Gotman, Right hippocampal excision impairs learning and recall of a list of abstract designs, Pages 659–670, Copyright (1986), with permission from Elsevier.


List of Figures

10.6 Time delay memory task and behavioral results. Reprinted from *Current Biology*, Volume 16, Stephanie J. Babb and Jonathan D. Crystal, Episodic-like memory in the rat, Pages 1317–1321, Copyright (2006), with permission from Elsevier. 211


11.2 Face processing and shape processing fMRI activity. Reprinted from *NeuroImage*, Volume 83, Scott D. Slotnick and Rachel C. White, The fusiform face area responds equivalently to faces and abstract shapes in the left and central visual fields, Pages 408–417, Copyright (2013), with permission from Elsevier. 223

11.3 Number of fMRI and ERP articles in the highest-impact cognitive neuroscience journals. 225

11.4 Brain region interaction TMS target sites and fMRI visual sensory effects during perception. Reprinted from *Current Biology*, Volume 16, Christian C. Ruff, Felix Blankenburg, Otto Bjoertomt, Sven Bestmann, Elliot Freeman, John-Dylan Haynes, Geraint Rees, Oliver Josephs, Ralf Deichmann, and John Driver, Concurrent TMS-fMRI and psychophysics reveal frontal influences on human retinotopic visual cortex, Pages 1479–1488, Copyright (2006), with permission from Elsevier. 228

11.5 Brain region interaction TMS target site, visual sensory regions of interest, and fMRI effects during working memory. Reprinted from *Proceedings of the National Academy of Sciences of the United States of America*, Volume 108, Eva
Feredoes, Klaartje Heinen, Nikolaus Weiskopf, Christian Ruff, and John Driver, Causal evidence for frontal involvement in memory target maintenance by posterior brain areas during distractor interference of visual working memory, Pages 17510–17515, Copyright (2011) National Academy of Sciences, USA.

11.6 The relationships between the fields of cognitive psychology, cognitive neuroscience, and behavioral neuroscience in the past and in the future.
Preface

The human brain and memory are two of the most complex and fascinating systems in existence. Within the last two decades, the cognitive neuroscience of memory has begun to thrive with the advent of techniques that can non-invasively measure human brain activity with high spatial resolution and high temporal resolution.

This is the first book to provide a comprehensive treatment of the cognitive neuroscience of memory. It is related to three classes of other books. First, textbooks on cognitive psychology or cognition provide broad overviews of the cognitive psychology of memory and therefore only consider a small fraction of the work on the cognitive neuroscience of memory. Second, textbooks on cognitive neuroscience provide broad overviews of the entire field and also consider only a small fraction of the work on memory. Third, more specialized books on memory focus on the cognitive psychology, the behavioral neuroscience, or the computational modeling of memory rather than the cognitive neuroscience of memory.

This book highlights temporal processing in the brain. Cognitive neuroscientists predominantly use functional magnetic resonance imaging (fMRI) to identify the brain regions associated with a cognitive process. Although fMRI has excellent spatial resolution, this method provides little if any information about the time at which brain regions are active or the way in which different brain regions interact. By emphasizing both spatial and temporal aspects of brain processing, this book provides a complete overview of the cognitive neuroscience of memory and aims to guide the future of memory research.

Each chapter is written in an accessible style and includes background information and many figures. Debated topics are discussed throughout the text. The most popular view is routinely questioned rather than simply assumed to be correct, as is done in the vast majority of textbooks. In this way, science is depicted as open to question, evolving, and exciting.

The audience for this book is educated lay people interested in the cognitive neuroscience of memory and undergraduate students, graduate students, and scientists who are interested in a comprehensive up-to-date treatment of this topic. Each chapter includes learning objectives, an introduction, sections on key topics, a summary, review questions, and
recommended scientific articles. At a college or university, this book could serve as a supplemental textbook in lower-level courses (for instructors who desire a comprehensive treatment on this topic) or as a main text in an intermediate-level undergraduate course, an advanced-level undergraduate course, or a graduate seminar (with instructor lectures, student presentations, and discussions of the recommended scientific articles).

Many individuals significantly improved the quality of this book. First and foremost, I thank Matthew Bennet, my editor. Without his vision, guidance, and support, this book would not exist. I am grateful to Jessica Karanian, Brittany Jeye, and two anonymous reviewers for providing invaluable comments and suggestions on the entire book. I thank Elizabeth Chua for her expert comments on the transcranial direct current stimulation section (and for providing a photograph illustrating this technique) and Lauren Moo for her insightful comments on the explicit memory and disease chapter. Finally, I thank Jacqueline French for her skilled copy editing and appreciate all of the professionals at Cambridge University Press, including Valerie Appleby, Brianda Reyes, Srilakshmi Gobidass, and Maree Williams-Smith, who made the production of this book a smooth process.