# THE OXFORD HANDBOOK OF MEMORY

EDITED BY
Endel Tulving
Fergus I. M. Craik

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OXFORD
UNIVERSITY PRESS

2000

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Oxford New York

Athens Auckland Bangkok Bogotá Buenos Aires Calcutta
Cape Town Chennai Dar es Salaam Delhi Florence Hong Kong Istanbul
Karachi Kuala Lumpur Madrid Melbourne Mexico City Mumbai
Nairobi Paris São Paulo Singapore Taipei Tokyo Toronto Warsaw

and associated companies in
Berlin Ibadan



Published by Oxford University Press, Inc.
198 Madison Avenue, New York, New York 10016

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Library of Congress Cataloging-in-Publication Data
The Oxford handbook of memory / edited by
Endel Tulving, Fergus I. M. Craik.
p. cm.
Includes bibliographical references and index.
ISBN 0-19-512265-8
1. Memory. I. Tulving, Endel.
II. Craik, Fergus I. M.
BF371.084 2000
153.1'2—dc21 99-27533

9 8 7 6 5 4 3 2 1

Printed in the United States of America
on acid-free paper

# Preface

Memory is usually thought of as the ability to recollect past events and to bring learned facts and ideas back to mind. Memory and learning have these functions indeed, but an adequate definition must necessarily bring in further aspects. For example, whereas past happenings may be re-experienced consciously, they can also affect behavior in the absence of such conscious awareness. In addition, the mental activities of learning and memory clearly have their neural counterparts in brain activities, and a full understanding of memory and related functions must therefore involve an understanding of the brain mechanisms of acquisition, storage, and retrieval. Recent scientific studies thus deal with memory and learning at the levels of experience, behavior, and neural mechanisms; each level can be understood in its own terms, but any final theory must also show how the different levels of description map onto each other. Because memory and learning are such all-pervasive shapers of human existence, their scientific study has never been far from center stage in experimental psychology and related brain sciences.

Memory reaches its evolutionary culmination in human beings. Human memory has been systematically studied for over a hundred years, and a great deal has been found out about its nature, functions, and manifestations. This has become possible through the invention and adoption of clever methods suitable for the objective analysis of something as ineffable as memory. Much of the success of these methods has consisted in meticulous delineation and elaboration of facts about memory that would not surprise anyone, but a good deal has involved the discovery of aspects that for long had remained hidden not only from the "expert users of memory," that is, ordinary people in everyday life—but also from the more interested and focused professional investigators.

The result of these activities is a massive, rich, and rapidly expanding accumulation of knowledge about memory in its many forms, together with continually increasing ability and sophistication in the development and adoption of tools required to add to this knowledge, and to make theoretical sense of it. An important characteristic of the factual data base of memory is its remarkable reliability. In a world as complex as that of memory it would be natural to think that observations about it sometimes take the form of "now you see it, now you do not." But as in a number of other established branches of psychology, accepted facts about memory are remarkably firm. When an expert claims that under such and such conditions such and such occurs, because this is what objective study has shown, there are seldom reasons to question the

claim. The uncertain parts of our science—and there are always some such in every living and growing enterprise—have to do with theory, with the question of how best to interpret and integrate the massive amounts of data that experimental and clinical studies of memory have yielded. This is where the present challenge lies, and will continue to lie for some time to come.

*The Oxford Handbook of Memory* was put together to summarize the current state of the science of memory. It was meant to inform the reader what this science is all about, how memory has been and is being studied, where the action has been, what the study of memory has achieved in the past, and where we are likely to go from here. Strictly speaking, the *Handbook* is not concerned as much with memory as it is with its scientific study. A more accurate title for it therefore might have been something like "The Oxford Handbook of the Scientific Study of Memory." But in addition to being awkward, this title probably would have frightened away many a potential reader who might find something interesting or even useful in the volume. Hence the short version of the title.

The *Handbook* deals largely with memory as seen from the perspectives of experimental psychology and its contemporary offshoots—cognitive psychology, neuropsychology, developmental psychology, and cognitive neuroscience. These perspectives deal primarily with human memory and treat it from the behavioral and cognitive points of view. For practical reasons alone—the amount of the material, the breadth of the expected readership, the expertise of the editors—it was not possible to embrace the equally successful and voluminous memory research conducted with other animals and at other biological levels of analysis. Even in the narrower field of "systems-level analysis" of human memory, work in several lively subareas had to be omitted from the present volume for what might be called technical reasons.

Given the exciting, rich, and vast field of memory, it may sound odd that this is the first handbook of memory ever published. There are thousands of books on memory, and thousands of handbooks on all other subjects, but, until now, there has never been a *handbook* of memory. Why not?

Like any other question of this sort, this one allows many possible answers. The one we like is that much of the early work now classified under "memory" was originally called something else. Until the 1960s memory in its current sense was researched, and written about, but mostly apologetically and unobtrusively. Until then the fashionable word, at least in North American psychology, was "learning"; and, indeed, various handbooks of learning were published. After about 1970, more and more psychologists began studying "memory" rather than "learning." They also began making new discoveries about memory, and having new ideas of a kind that would not fit into the learning framework. In no time at all memory became a tremendously successful growth industry. Because of the feverish pace at which research on memory was conducted, and new things about memory discovered, its practitioners were simply too busy to find time to write about old "solid" achievements, the typical fare one expects to find in volumes labeled "Handbook."

This, at least, is one possible explanation of why the present volume is the first handbook of memory ever published. The research area of human memory and learning is a vast one, and the *Handbook* does not attempt to deal with all possible aspects. We did, however, try to cover the major theories, findings, and methods that are current in the more restricted field of memory, especially those associated with the perspectives of cognitive psychology and cognitive neuroscience.

The scope of the *Handbook* is reflected in the organization of its sections. Part I sets the scene for the rest of the book by laying out some basic presuppositions, concepts, and methods in a historical context. Part II is concerned with memory in the laboratory—how memory has been studied from the "verbal learning" and "cognitive" standpoints. This section provides a survey of the major hypotheses, methods, results, and conclusions that form the central core of work on memory at the present time. The level of analysis in such laboratory studies has traditionally been that of behavior, but more recent work has emphasized the roles of conscious awareness and reflection, so these perspectives are also given due prominence.

Part III deals with memory in the real world as opposed to in the laboratory. It covers the development of memory in infancy and childhood, and also the decline of memory seen in normal aging and in some pathological conditions. This section also contains chapters on personal memories for events and knowledge, on spatial memory, and on the role of emotion. The final section contains two sets of

chapters. Those in the first set describe the fascinating current work that links the behavioral and experiential aspects of memory to brain mechanisms; it is not an exaggeration to say that the new technologies of neuroimaging have revolutionized this approach to the study of memory, and that the area is one of the most exciting and dynamic in present-day science. The chapters in the second set bring many of the previously described findings and ideas together under the heading of current theories, which again reflect the experiential, behavioral, and neural levels of analysis. Finally—the culmination of our "39 steps to wisdom"!—Larry Weiskrantz provides some reflections on the whole enterprise.

A word about responsibility, or accountability. The editors are responsible for the general contents and the organization of the volume, as well as the selection of the authors of individual chapters. It is worth noting that every author who was invited accepted the challenge of the task presented to him or her. This means that as far as the editors were concerned they were working with the "first team." The authors were given general guidelines as to the nature of the whole enterprise (intended audience, level of writing) and the quantitative scope of their chapters, but otherwise were left free to "do their own thing." By and large, however, the editors did not meddle with what the writers wanted to say.

All this means that the editors do not take, cannot take, any responsibility for the actual substantive contents of individual chapters. In a field as much in flux as is memory, a field that is still struggling to find its first Kuhnian paradigm, a field in which theories vie with facts for the observers' attention, it is impossible for any collection of writers to put together a menu that pleases every reader, be the reader the editor of the collection, a happy owner of the *Handbook*, or an equally happy borrower of it in the library. There are things said by writers of chapters that the editors do not believe or do not approve of, in addition to the majority of things that they do. These matters will be discussed in the ordinary course of scientific "business"—interchanges at scientific meetings, on the pages of specialty journals, and by personal correspondence. Readers of the Handbook are invited to initiate and partake in such discussions. The current snail-mail and e-mail addresses of all the authors are given at the beginning of the volume.

As is always the case in the creation of serious books we too are happy to acknowledge the gracious help of many people "without whom this book could not have happened," as the saying goes. Our most heartfelt thanks go, of course, to our colleagues and friends who accepted our invitation to contribute to the *Handbook*. We are very pleased that we were able to rely on the expertise, knowledge, and skills of such an outstanding collection of individuals. We expect the *Handbook* to become a major reference source for people who want to get started in the field, or who wish to check things outside their own regional area. Such an ambition can become reality only if the source of the information lies in the expertise of the most qualified writers on every topic.

Among others "without whom," we especially wish to express our gratitude to Alison Mudditt who, out of the blue, provided the initial spark for the whole venture. We are also most grateful to Joan Bossert, the Executive Editor at the Oxford University Press who was most enthusiastic, encouraging, and helpful with a number of details from the very beginning, and whose continued support has been essential throughout the venture. Our very special gratitude goes to Sharyn Kreuger, who provided invaluable help in the closing stages of editing and checking manuscripts. Finally, we acknowledge the less visible but equally important contributions of the many parents, teachers, spouses, colleagues, and students of the people who have written chapters for the *Handbook*. We regret that it is not possible to mention them all by name, but we do sincerely thank them all, not only on our behalf and that of the authors of the chapters, but also on behalf of the many prospective readers and users of *The Oxford Handbook of Memory*.

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# Contents

# Part I: Study of Memory

# 1

# A Brief History of Memory Research

GORDON H. BOWER

## Background: Associationism

Psychology as a discipline developed out of philosophical discussions regarding the nature of the mind and mental life. The study of memory and learning arose from philosophical questions regarding how people come to know things about their world. Learning is assuredly the primary way we acquire knowledge, and remembering is a primary means by which people support knowledge claims, as when a witness in court asserts "I remember seeing Jones with a revolver in his hand."

Philosophical speculations about learning were prominent among advocates of *empiricism*, which is the view that sensory experiences are the only ultimate source of knowledge and truths about the world (contra innate ideas or religious authorities). People's ideas about the world are alleged to derive from sense impressions either as simple copies or as combinations of simple ideas. Objects such as oranges, dogs, and houses are allegedly constellations of many sensory qualities (e.g., the color, shape, taste, and texture of an orange).

The empiricist program required some means for learning these constellations. Thus was introduced the fundamental theory of *association by contiguity* (Warren, 1921). Complex ideas are allegedly formed in the mind by connecting together in memory simple ideas based on sensations that are experienced contiguously in time and/or space. The memory that sensory quality or event A was experienced together with, or immediately preceding, sensory quality or event B is recorded in the memory bank as an *association* from idea *a* to idea *b*. Reviving these associative sequences from memory (when recurrence of event A makes us think of event B) is the presumed method by which people's past experiences cause their later thoughts to progress from one idea to the next. This basic notion can be elaborated to account for the way humans develop coordinated expectations about properties of objects, expectations about causal sequences of events, predictions about future events, explanations of how or why something came about, and plans of action designed to bring about particular outcomes. These are basic abilities of the mind.

Throughout the seventeenth to nineteenth centuries, empiricist philosophers such as John Locke, John Stuart Mill, and Thomas Brown speculated about various factors that might affect the degree or strength of particular associations (Warren, 1921). They recognized that associations would vary in their strength according to the *vividness* or distinctiveness of the original experience, its *duration* (study time), its *frequency* (repetitions),

and its *interest* for the observer. Revival of associations from memory was hypothesized to vary with the *resemblance* of the stimulating cue to the memory, the *recency* of the experience, the coexistence of *fewer alternative associates* to the cue (called "interference"), and "*temporary diversities of state*" (intoxication, delirium, depression). Such conjectures have generated much experimental research on learning and memory, and every learning theory deals with these factors in some way (Bower & Hilgard, 1981).

The scientific investigation of association formation began with the work of a German scientist, Hermann Ebbinghaus, whose pioneering research (with himself as sole subject) was published in his treatise *On Memory* in 1885. Discussion of his work will be postponed in order to examine briefly another major influence on studies of learning—namely, the doctrine of *behaviorism*, which became wedded for many years to the doctrine of associationism.

## Behaviorism and S-R Psychology

### *The Behaviorist Philosophy*

Behaviorism is a positivist philosophy which argues that all that observers can ever know about other persons or animals is provided by close observations of their overt actions or behaviors in specific situations (and human behavior includes speech). Behaviorism grew out of a desire for scientific objectivity in observations and for parsimony in explanations; it was especially critical of the undisciplined, introspective "mentalism" that at the turn of the century was being passed off as an explanation for behavior. On the behaviorist view, to predict someone's behavior, all one needs is a catalog of specific facts and generalizations about his or her past responses to situations resembling the present one. These generalizations about a person's past situation-to-action regularities are presumably carried in his or her nervous system as a set of stimulus-response (S-R) *habits*.

### *Antecedents of Behaviorism*

While antecedents to behaviorism were many, an assured one was Charles Darwin's theory of biological evolution, which suggested the continuity of all species, including *Homo sapiens* (Darwin, 1859). Human learning was seen as an adaptive mechanism that evolved over millions of years throughout the animal kingdom by small variations and minor accretions in the neural hardware that carries out the various learning tasks with which organisms are confronted. This "biological continuity" view justifies the many comparative studies by psychologists of behavioral adaptation and learning in lower animals. Since animals do not talk, those studies led in turn to a strong behaviorist orientation toward learning. Thus, learning came to be viewed as a change in an organism's behavioral dispositions in particular situations (S-R habits) as a result of its experiences. It was recognized, of course, that the responses may be complex skills and the stimuli may be those stemming from a complex environment, including intricate and subtle social situations.

Behaviorist approaches to learning were greatly encouraged around the turn of the twentieth century by the pioneering studies of conditioned reflexes by the Russian physiologist Ivan Pavlov (1927) and by early studies of "trial-and-error" (instrumental) learning by Edward Thorndike (1898, 1903), an influential educational psychologist in America. This behaviorist orientation was promulgated by many influential psychologists throughout the first half of the twentieth century—from John Watson (1919, 1924), to Clark Hull (1943), to B. F. Skinner (1953, 1957). This orientation strongly affected the way in which human learning was studied and explained. That orientation began to fade with the coming of the "cognitive revolution" that began in the late 1950s and early 1960s. However, before discussing those events, we return to the earlier work of Hermann Ebbinghaus and the rote learning tradition that followed his pioneering studies. The rote learning tradition was characterized by a fusion of associationism and behaviorism.

## Ebbinghaus and the Rote Learning Tradition

Ebbinghaus (1885) set out to investigate the formation of novel associations using controlled systematic experiments with careful measurements of his own learning. He introduced strict controls regarding the timing and number of study trials, recall time permitted, and retention interval (to study forgetting). He invented the notion of the nonsense syllable

(like DAX, QEH) to provide himself with learning materials of homogeneous difficulty, thus avoiding the variability of familiar words or prose. He taught himself by studying serial lists of 6 to 20 syllables, reading them aloud in sequence in pace with a metronome and then trying to recite the series from memory. The serial list was his analog of the associative chain of ideas about which philosophers had speculated.

Ebbinghaus introduced many important ideas and methods (see the Ebbinghaus symposium published in the July 1985 issue (volume 11) of the *Journal of Experimental Psychology: Learning, Memory, and Cognition*). He measured the difficulty of learning a list by the number of study trials required for him to attain one errorless recitation of it. He noted how difficulty increased disproportionately with the length of the list being learned. He introduced the idea of measurable "degrees of learning" (or forgetting) by noting the savings in relearning a list he had learned earlier. The percent savings was the difference in trials for original learning (say, 9 trials) minus those needed for later relearning (say, 3) divided by the original learning trials (so, $(9 - 3)/9 = 67\%$). Using this measure, he was able to plot his famous forgetting curve relating percent savings to retention interval. This curve (figure 1.1) showed very rapid losses over the first few hours or days, with more gradual but steady decline over subsequent days, weeks, and months. Ebbinghaus also found that forgetting of a list decreased with multiple relearnings of it, that overlearning increased retention, and that widely distributed study trials (say, 1 per hour) were more effective than closely packed trials (say, 1 per minute) for long-term retention.

Ebbinghaus's new paradigm (adults learning lists of nonsense materials) defined a task in which a multitude of variables can be defined and their influences on "remembering" behaviors observed. The phenomena that he discovered, his ideas, and his methods cast a long shadow throughout the twentieth century of research on human memory. Subsequent research has invented several other paradigms and teased out many variables that determine memory performance in these settings. The memories established can be tested by either recall, recognition, and reconstruction, or by a variety of indirect measures. The nature of the materials can be varied, as can their mode of presentation, strategies subjects use in studying them, expectations regarding the memory test, and relationships among several sets of materials being learned. As variables have been isolated and studied, a huge backlog of empirical information has accumulated about how humans learn in these situations. And many theoretical hypotheses have been proposed and tested to integrate and account for the evidence surrounding specific topics.

## *Analysis of Laboratory Rote Learning Tasks*

The rote learning tradition was established around the intensive study of three different kinds of learning paradigms—serial learning, paired-associate learning, and perceptual–motor skill learning. We will briefly characterize each of these learning tasks and a few of their findings.

### Serial Learning

The task Ebbinghaus used is called *serial learning*, an analog of learning the alphabet or learning to put letters in sequence to spell a word: the subject learns to output in a specified order a small set of temporally ordered, discrete items (letters, nonsense syllables, written or spoken words, pictured objects, sentences). Subjects are asked to remember both the items and their serial order. Retrieval may be tested by asking subjects either to reproduce (recall) all items in the order presented, or to recall what item followed a specific cued item, or to reconstruct the presented order when given the items (on flashcards) in scrambled order. In some experiments, a number of series are presented only once for recall (e.g., for measuring the immediate memory span). In other experiments, the same items may be presented many times in the same order for repeated study and test trials to examine accumulative learning.

Studies of serial learning have uncovered many facts. Increasing the study trials and time per item increases learning; increasing the time subjects are given to anticipate the next successor in the series improves their performance. While making the items very similar to one another (e.g., XON, NEH, XEH, NOH) improves their recallability, this similarity creates many confusion errors about their ordering. A robust finding is that items at the beginning and end of the list are easier to learn than items in the middle (see figure 1.2), a fact that has provoked many explanatory attempts (Johnson, 1991).