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REMEMBERING

An Activity of Mind and Brain

Fergus I. M. Craik

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An Activity of Mind and Brain

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To Anne

Preface

This book has had a long gestation period. I first had the idea of writing a book on memory when I applied for a Killam Research Fellowship in 1981. These excellent Fellowships are awarded by the Canada Council for the Arts to Canadian scholars from universities and research institutes "to pursue groundbreaking research" for two years, untrammeled by normal teaching and administrative duties. In my application I stated my intention to write a "groundbreaking book on memory" while spending a year at the Center for Advanced Studies in the Behavioral Sciences at Stanford University, and this aspiration seemed to impress the Killam selection committee. So I spent an interesting year at the Stanford Center, writing up completed studies, lunching in the Californian sunshine, discussing aspects of memory theory with a congenial group of researchers (see Chapters 2 and 7), but unfortunately – no book! The intention then lay dormant for several years, until I began thinking about it seriously again in early 2017. By this time the idea had morphed from a rather vague hypothetical construct to a more definite plan. My career as an experimental psychologist was clearly drawing to a close, so it was appealing to write up many of the studies I had done over the years with a view to highlighting the theoretical ideas that lay behind the experiments, how the ideas had evolved, and how they made contact with current concepts in cognition and cognitive neuroscience. Progress over the next couple of years was somewhat sporadic, but in March 2020 the Covid-19 pandemic arrived in Canada. Like everyone else I was confined to quarters – nothing to do but write! – and so the 40-year project was finally completed.

The book is partly a record of my own experimental work in memory, attention and aging research over 50-plus years, augmented by descriptions and discussions of relevant studies by colleagues and collaborators, and partly a discussion of how theoretical ideas have changed over the years with the advent of new technologies and new concepts from neighboring disciplines. So it is not a comprehensive textbook of memory; rather, the emphasis is on empirical issues and theoretical puzzles that have caught my attention from the mid-1960s to the present day. The main theme is the idea that human memory should be thought of as a mental *activity* rather than as a 'thing in the head' – as the verb 'remembering' rather than the noun 'memory.' The book's title *Remembering: An activity of mind and brain* intends to capture this central point, and I have traced my own thinking along these lines from the cognitive work on levels of processing with Robert Lockhart and Endel Tulving to current collaborative work with colleagues at the Rotman Research Institute involving neuroimaging and neural networks. I should emphasize that although the word 'brain' is in the title, the contents focus very largely on cognitive, behavioral studies. However, one cheering aspect of current work in cognitive neuroscience is the extent to which constructs emerging from cognitive studies – attention, working memory, perception/memory interactions etc. – are guiding and organizing current work on brain processes.

With its focus on my own work (and its implications for the rest of the field) the book is therefore modeled on such previous classics as Endel Tulving's 1983 book on episodic memory and Alan Baddeley's books on working memory, in the sense that it is a personal view of attention, memory and learning. In greater detail, the book starts with a description of the ideas and experiments that led to the 1972 article on levels of processing by Craik and Lockhart and to the 1975 empirical article by Craik and Tulving. From my perspective these ideas arose directly from work on attention by the English psychologists Donald Broadbent and Anne Treisman, so their seminal ideas are sketched briefly. Chapter 2 discusses some historical and more recent ideas on remembering as an activity of mind. One less familiar source in this context is the Russian work stemming from the activity theories of Vygotsky and his colleagues. The work on memory from this perspective by such researchers as P. I. Zinchenko and A. A. Smirnov in the 1940s and 1950s is really *quite* similar to the ideas proposed some decades later by Craik and Lockhart (as emphasized by some trenchant Russian critics!), although the starting points for the two sets of ideas were quite different. Chapter 3 is an attempt to flesh out my ideas on remembering as a processing activity, and so sets the scene for work discussed in the following chapters.

Chapters 4 and 5 deal respectively with the activities of encoding and retrieval, although it quickly becomes apparent that the two sets of processes are intimately related and simply cannot be described in isolation; retrieval processes are in many ways the mirror image of encoding processes. Chapter 6 covers experiments and theoretical ideas on short-term memory, and how the focus in this area turned progressively to the more current notion of working memory. Chapters 7 and 8 describe some experiments and concepts in the area of cognitive aging, again with a focus on age-related differences in remembering. This topic has been a strong second interest of mine throughout my career, so a lot of ground is covered. I therefore split the descriptions into two chapters, in order not to tax the reader's patience too severely. Chapter 7 mainly sets out a number of theoretical ideas, while Chapter 8 focuses more on empirical studies. After a good deal of Scottish 'swithering' I finally decided to include a chapter on the brain (Chapter 9). Early reviewers were divided in their advice on this point, with some suggesting that "Craik should stick to what he actually knows about!" and others pointing to the strong emphasis on neuroscience in current work on memory. I have been involved as a collaborator on many neuroimaging studies since the early 1990s, so I eventually decided to include the chapter. Finally, Chapter 10 draws several research lines together, summarizes the main arguments, and hopefully makes contact with a number of current issues in human memory research.

In overview, the book is essentially a research monograph focusing on work in my lab over 50 years or so, and how that work relates to other ideas and findings in the field of human memory research. It does not attempt to cover studies of human memory comprehensively, but will hopefully involve readers in a wide range of interesting topics. Although a number of the experiments described are 'historical' at this point, I believe that the main ideas are still very current. The book is aimed principally at research colleagues, from graduate students to seasoned professionals, but I have also tried to keep the descriptions accessible, so I am hopeful that more general readers may catch some of the excitement associated with the findings and ideas. The tone is informal and somewhat 'chatty' – my normal writing style, for better or for worse!

The work described in this book could not have been carried out without the support from many individuals and institutions. My lab work on attention and memory has been generously supported over many years by the Natural Sciences and Engineering Council of Canada (NSERC), augmented by funds from the Killam Trusts and from the University of Toronto. I have greatly benefited over the years from the stimulation provided by the rather grandly entitled Ebbinghaus Empire; a research seminar on topics in memory and cognition, meeting weekly in the Psychology Department of U of T. When I first arrived in Toronto the stern co-Emperors were Ben Murdock and Endel Tulving, presiding over a respectful and mostly silent group of graduate students and postdocs. The silence (although not of course the respect) was finally broken in the early 1970s with the addition of Bob Lockhart, Morris Moscovitch and others to the group, and the 'EE' remains a terrific source of new ideas. I also profited from similar groups in London – a seminar organized with Tim Shallice from UCL – and at Erindale College; a joint Erindale-McMaster group run by Larry Jacoby and myself.

With regard to the many individuals who have helped to formulate my ideas and to guide my career I can pick out several who have been particularly influential. This group includes Ellen Bialystok, Larry Jacoby, Betty Ann Levy, Robert Lockhart, Morris Moscovitch, Moshe Naveh-Benjamin, Donald Stuss, Endel Tulving and Boris Velichkovsky; I am truly grateful for their support, wise guidance and inspiration over the years. At the present time I am fortunate to have outstanding colleagues at the Rotman Research Institute at Baycrest in Toronto. It is a very interactive group of scientists, and I have collaborated on published papers with many of them. I have enjoyed working with them all and learned a lot from our interactions.

I have also been extremely fortunate in the students, postdoctoral fellows, research assistants and visitors who have made up my labs in London and Toronto. I have particularly fond memories of my lab at Erindale College in the late 1970s and early 1980s. We called the lab 'The LMR' for obscure reasons. It was a very

productive group, with many ideas for experiments thrashed out in the local pub! Other lab members who have greatly influenced my thinking over the years include my excellent graduate students at Birkbeck College in London, whose work is described in the book; also the graduate students, postdoctoral fellows and international visitors who have populated my labs at Erindale College, the main campus at U of T, and the Rotman Institute. I am greatly indebted to them all.

The book's final form has been greatly influenced by the heroic efforts of three good friends; Ellen Bialystok, Larry Jacoby and Bob Lockhart, who each read the complete draft, chapter by painful chapter. I am immensely grateful for their wise counsel at every level from commas to concepts; the finished product is hugely improved by their suggestions. I also received some very helpful guidance from several anonymous reviewers appointed by potential publishers; I very much appreciated their (mostly!) kind comments. Two reviewers who revealed their names are Roddy Roediger and Morris Goldsmith. I am grateful to them both. I can add that Morris Goldsmith went way beyond the call of duty by producing 20 single-spaced pages of detailed comments and suggestions. A jaw-dropping effort, and very much appreciated.

I am very grateful to Kevin Tang, a research assistant in my lab, who did a splendid job of compiling the long list of references. And I must say a special word of thanks to Jennie Sawula who typed up the great bulk of the manuscript. I have to confess to a medieval style of scientific writing – I still write everything in longhand, barely a step beyond scratching it out laboriously with a quill pen on vellum. However, I then ingeniously harness modern technology by FAXing each completed sheet to Jennie, who deciphers my scrawl, types it up on Word and sends it back by email for final editing. Bizarre but effective! Thank you Jennie!

I am also very grateful to the team at Oxford University Press who steered me through the publication process with commendable efficiency and graciousness. My first helpful contact was with Martin Baum and James Oates; production was handled by Karen Moore, with copyediting by Jayne MacArthur and indexing by Sue Leech. I am greatly indebted to all of them.

Above all, I have to thank my family for putting up with my endless scribbling at times when I should have been out throwing footballs with my son, taking my daughter to ballet lessons, driving my grandchildren to the beach, or whatever it is that better fathers and grandfathers do. When my children were teenagers, a friend asked them "Is your father an actual workaholic?" *Now* things will be different! Finally, this book is dedicated to my wife Anne, who graduated from being a subject in one of my early experiments to being a wife, mother and loving companion on trips to the opera and walks in the Alps. Thank you for everything.

Contents

Abbreviations

ABM	autobiographical memory
AG	aerobic glycolysis
ANOVA	analysis of variance
APA	American Pyschological Association
CP	cue at presentation
CR	cued recall
CRT	continuous reaction time
DA	divided attention
DMN	default mode network
DRM	Deese–Roediger–McDermott
EEG	electroencephalogram
FA	full attention
fMRI	functional magnetic resonance imaging
HERA	hemispheric encoding/retrieval asymmetry
LOP	levels of processing
LSD	least significant difference
LTM	long-term memory
MLI	momentary lapse of intention
MRC	Medical Research Council
MVPA	multivoxel pattern analysis
NCR	non-cued recall
PDP	process dissociation procedure
PET	positron emission tomography
PFC	prefrontal cortex
PI	proactive interference
PLS	partial least squares
PM	primary memory
PRS	perceptual representation system
PTSD	post-traumatic stress disorder
RT	reaction time
SM	secondary memory
SO	subjective organization
SPM	statistical parametric mapping
SPT	subject-performed task
STM	short-term memory
STS	short-term store
TAP	transfer-appropriate processing
TOT	tip of the tongue
UC	University of California

VT	verbal task
VWM	visual working memory
WAIS-R	Wechsler Adult Intelligence Scale – Revised
WCST	Wisconsin Card Sorting Test
WFC	word fragment completion
WM	working memory
WMC	working memory capacity

1
Levels of Processing
Development of an Idea

Introduction

The major purpose of this book is to examine the proposition that human memory should be regarded as an activity of mind and brain. This perspective stands in contrast to accounts in terms of structures; as items and associations for example, or as memory stores. The present approach is thus a processing account—remembering as a set of processes—with encoding and retrieval processes viewed as activities that can be described in both behavioral and neural terms. A secondary theme is to explore how far it is possible to stretch the idea that remembering is basically a form of perceiving and thinking, with encoding processes being nothing more than the normal activities of perceiving, comprehending, thinking, and deciding, and with retrieval processes being essentially an attempt on the organism's part to recapitulate the same pattern of processing that took place during encoding. I would like to believe, in fact, that the processing view can be extended to cognition generally, although the present account will focus more narrowly on attending and remembering.

The view of human memory that I will set out suggests that (following Bartlett, 1932) we should talk of *remembering* as a mental activity rather than *memory* as a stored record. Along with many other researchers I will emphasize the similarity between encoding and retrieval processes—basically that retrieval is an attempt to recapitulate encoding—and that both sets of processes are, in turn, similar to the processes of perception and comprehension. I will argue, in fact, that "memory" consists essentially of modifications to these perceptual and conceptual systems, especially at higher levels of analysis. Whereas perceiving obviously reflects an interaction between incoming sense data and existing analytic and interpretive processes, my proposal is that remembering does also—although with a focus on the evoked internal representations rather than on the interpretation of external sense data. According to this view retrieval does not consist of a search through many stored records (the library analogy), but is the product of an interaction between current input in the form of sensory information plus questions, cues, and context, and the previously modified perceptual/conceptual analytic mechanisms (my version of "the memory trace"). My colleague Bob Lockhart suggested that a more appropriate analogy is the example of a tree falling in the forest—does it

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make a sound if nobody is present? At first it seems obvious that the answer is "yes"—surely the sound waves occur regardless of the audience. But the waves by themselves make no *sound*, so the correct answer is "no"—the *experience* of a sound requires an interaction between the physical sound waves and the auditory sensory system of a listener, just as remembering requires an interaction between a question or other input and the existing analytic mechanisms. Hopefully these rather arcane ideas will become clearer as the chapters unfold!

I should also say a few words about my use of the word "remembering," which is prominent in the book's title and throughout the chapters. Remembering refers to the activities involved in retrieving information of different types and for different purposes; it does not have to be deliberate, however, as "involuntary remembering" clearly occurs (Berntsen, 2010; see Chapter 5). It does typically refer to the *conscious awareness* of retrieved information, and this is the sense in which I mostly use the word. However, this usage apparently excludes such important categories as implicit and procedural memory, which I certainly intend to include in the general framework of remembering as an activity of mind. So, for the most part, I will use the word to connote the conscious experience associated with the retrieval of facts and events, but I also intend "remembering" in a looser sense to refer to the activities associated with the retrieval and use of *all* types of encoded information.

In general terms the book will set out what I believe about memory after studying it for many years. It is thus partly an account of some of my own studies as they relate to the central theme of "memory as activity" and partly a critical assessment of other studies—selected on the basis of their relevance to the overall theme. I will embed these descriptions of experiments, critical accounts, and theoretical speculations in a first-person autobiographical framework in order to provide context in terms of the people, places, and events that have influenced and shaped my thinking over the years.

The book starts with an account of the levels of processing framework proposed by Robert Lockhart and myself in 1972, followed by an assessment of how these ideas have fared in the light of subsequent theoretical and empirical advances. A second chapter describes a number of precursors to the levels of processing ideas, and examines how they fit the central theme of remembering as an activity. Further chapters deal with encoding and retrieval processes in greater detail, with the transition of the concept of short-term store to that of working memory, with age-related changes in memory, and with its neural correlates. A final chapter attempts to integrate the various findings and ideas into a coherent big picture account.

Levels of processing

In the late 1960s and early 1970s I was a faculty member in the Psychology Department of Birkbeck College, which is part of the University of London. British psychology at that time was considerably different from psychology in North America—largely because the behaviorist movement and its influence on theories of animal and human learning had never fully caught on. In Britain, the emphasis in experimental psychology was more on perception, motor skills, and higher-level cognition. The neuropsychological study of clinical patients was also prominent. Models of attention were popular—largely influenced by the seminal work of Donald Broadbent, whose ideas were set out in his 1958 book *Perception and Communication*. Broadbent's "filter theory" of attention was formulated to address the practical problem of errors made by machine operators working under conditions of information overload, specifically errors made by pilots of World War II aircraft. The errors were first attributed to carelessness or to inattention on the part of pilots, but Broadbent's view was that the errors reflected an inability of the human brain to deal simultaneously with a number of competing sources of information, regardless of whether the inputs were all visual or were visual and auditory. Broadbent argued that the brain has a limited capacity to process incoming streams of information and that an attentional mechanism selects one input channel and necessarily ignores others. As shown in Figure 1.1, Broadbent's filter theory proposed that incoming sensory information undergoes initial processing and is then held in a preconscious *s-system*. I assume that the *s-system* is more precisely a set

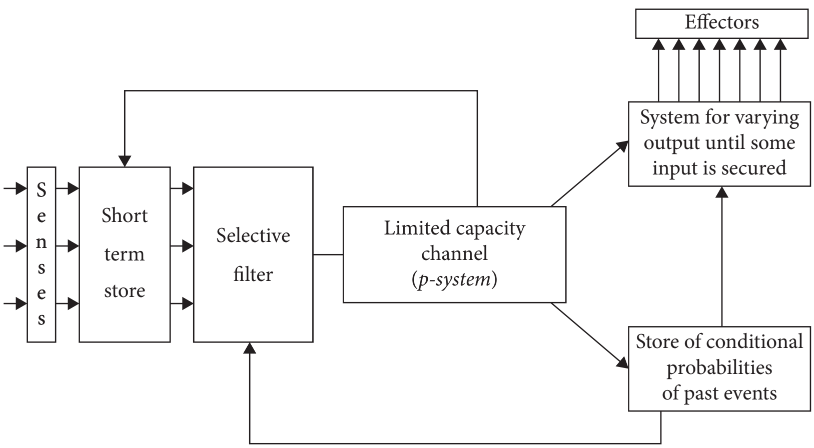

Fig. 1.1 Broadbent's filter theory (Broadbent, 1958, p. 299). All stimuli impinging on the senses enter the short-term store (*s-system*); the attentional filter selects one channel to be processed further in the limited-capacity *p-system*, which may be equated with primary memory and conscious awareness. Information in the *p-system* may be recirculated to the *s-system*; information also makes contact with knowledge in long-term memory (store of conditional probabilities of past events), and with potential actions back into the environment via appropriate effectors.

Reproduced from Broadbent, D. E., *Perception and Communication*, Pergamon Press Ltd. 1958 with permission from Elsevier.

of modality-specific sensory stores, but the main point is that *all* incoming information is partially analyzed and held briefly at that level. So the *s-system* is preattentive and has a large capacity but a rapid forgetting rate.

Broadbent's proposal was that an attentional mechanism then selects one incoming "channel" of information and passes it on for further processing and conscious awareness in the *p-system* ("*p*" for perception, I assume). This selective filter was assumed to act in an all-or-none manner—that is, it is "tuned" to select one channel and ignore all others. The basis for selection could be top-down (e.g., "listen to the right ear and ignore the left ear") or bottom-up (e.g., the selection switch might be attracted by a loud, bright, or otherwise salient stimulus stream). Once in the *p-system* the sensory information has access to previously acquired knowledge (long-term memory) and acquires meaning through rapid transactions with that knowledge. Broadbent also suggested that the information in the *p-system* (and thus "in mind") could also be rehearsed before being used to formulate a response and that rehearsal involves a recirculation of material through the *s-system* and back to the *p-system*.

The filter theory gave a good account of experiments involving two ears (dichotic listening) and also eye and ear (Broadbent, 1958), but was questioned by an observation made by the English psychologist Neville Moray. He found that when participants were fully engaged in "shadowing" (repeating back) auditory information presented to one ear, they had little or no knowledge of messages presented to the other ear—in line with Broadbent's model. If the unattended message contained the participant's own name, however, it was perceived on roughly one-third of occasions. This should not happen if the filter acts to block all unattended messages (Moray, 1959). The same problem was illustrated by a simple experiment reported by two undergraduates (Gray and Wedderburn, 1960). They showed that if two meaningful word triplets, such as "Who goes there?" and "My Aunt Jane" were presented dichotically so that the meaning switched from ear to ear, e.g., "Who Aunt there" in the right ear and "My goes Jane simultaneously in the left ear, participants reported hearing either "Who goes there?" or "My Aunt Jane" without realizing that they had switched ears during the message. Somehow meaningfulness switched the filter *before* the messages entered the *p-system*, and this just could not happen with an all-or-none switch located before meaning was assigned. An everyday parallel to this ingenious experiment is the experience of attending closely to one speaker (for example, at a "cocktail party"—much frequented by experimental psychologists in the 1950s it seems!), yet plainly hearing a highly significant fragment of conversation (the listener's own name, for instance) from a different speaker, whose conversation had otherwise not been heard or understood. Again, meaningfulness appears to act in a bottom-up manner, which gives problems to many models of attention viewed as a series of stages, with meaning allocated at a relatively late stage.

One solution is the suggestion that *all* inputs are analyzed to the level of meaning, and that selection takes place only after this full analysis. Such so-called "late-selection models" (e.g., Deutsch and Deutsch, 1963) seem biologically wasteful, however—given that most deep analyses of meaning will simply be discarded. A middle way was proposed by Anne Treisman in a series of papers (Treisman, 1964a,b). She suggested that selection takes place *throughout* the process of analysis, with only attended, salient, or highly meaningful messages surviving a progressive set of analytical stages to reach conscious awareness. The essence of Treisman's model is sketched in Figure 1.2. It comprises a series of "levels of analysis" running from shallow sensory analyses through intermediate analyses (e.g., of phonemes or simple visual forms) to deeper meaningful analyses of words, sentences, objects, and scenes. Each level of analysis functions as a pass–fail test, specific to that particular input. In Treisman's model conscious perception is

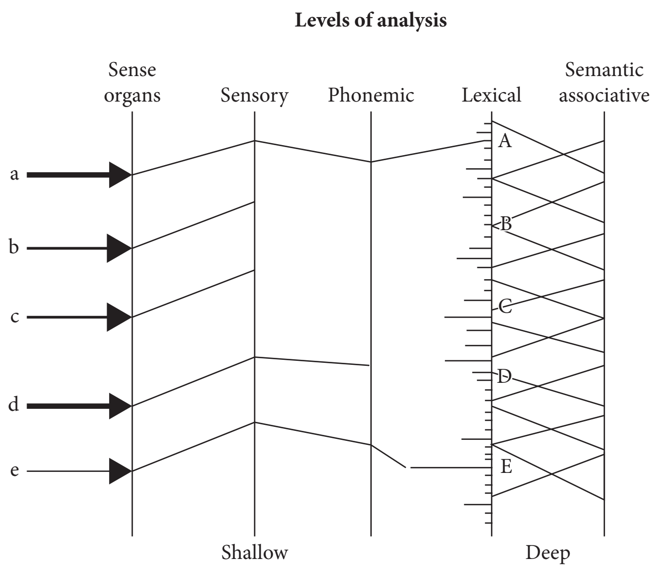

Fig. 1.2 My interpretation of Treisman's (1964a) model of attention. Incoming stimuli enter the processing system with various degrees of physical strength; they are then processed to various "depths of analysis" depending both on their initial strength and on their probability of occurrence in the current context. In the diagram, stimuli a, b, c, d, and e have registered in sense organs with various degrees of strength (shown here as line thickness). At the lexical level, the probability of a word's occurrence before stimulus onset is shown by length of line (e.g., A has a very low probability, E is highly probable). Stimulus a is processed deeply and activates A due to its incoming strength. Stimulus e is weak but is "drawn in" by the high probability of its corresponding word's occurrence. Stimuli b, c, and d are partially analyzed to various depths; the level attained determines which aspects of the stimulus are consciously perceived.

a correlate of the analyses being performed; that is, partial (typically early) analyses will be perceived even if the stimulus is not fully analyzed. So a listener may be aware that input from a second speaker is present on an unattended channel (e.g., the left, unattended ear in a dichotic listening experiment), and may even be aware that the speaker is a woman, yet have no awareness of the meaning of the unattended speaker's conversation.

Treisman further suggested that two sets of factors determine the fate of incoming stimuli. One set works bottom-up, and includes signal strength variables such as loudness and brightness. Paying attention to a particular input channel also has the effect of increasing the effective signal strength of stimuli on that channel. The second set works top-down and essentially reflects the probabilities of occurrence at that time of various possible stimulus inputs. Some stimuli are treated as permanently important to the person (e.g., the person's own name), others as important under specific circumstances (e.g., expecting a telephone call or being aware of a fretful baby), and yet others are given a high probability rating by a temporary context (e.g., after hearing "the boy leaned out the ______?", the word "window" becomes salient). Treisman proposed that the pass–fail tests at each level of analysis act like tests in signal detection theory (Swets et al., 1961) in which the criterion (ß) is set by temporary or long-lasting probabilities of occurrence, and signal strength (d') is set by the physical qualities of the input stimulus and by the deployment of attention to that channel. An incoming stimulus item will thus "pass the test" and proceed to deeper tests either if it is a strong signal or if the criterion "pass mark" is set to a lenient level.

By this scheme, incoming stimuli will be processed to a shallow or deep level according to the interplay of these two factors. Strong signals will "bulldoze" their way through to full conscious awareness, regardless of how probable or improbable they are at that moment, and highly probable stimuli will also be pulled through successive levels of analysis by virtue of top-down influences setting appropriate criteria at favorably low levels. Figure 1.2 depicts a situation in which several sources of stimulation are impinging on the system at one time. All inputs are registered at the earliest sensory levels of analysis, but they then proceed to deeper levels depending on their signal strength and probability of occurrence at that moment. Strong signals pass successive tests despite the fact that appropriate analytic criteria are not set in their favor but may not get through to a full analysis of meaning. Weak signals may fail early in the analytic sequence or proceed to a full analysis if their contents are probable in the current context. The perceptual end result is thus typically one in which messages from an attended source are fully analyzed and comprehended, while others are only partially analyzed but are nonetheless perceived in terms of their sensory characteristics.

I found one of Treisman's (1964c) experiments particularly intriguing. She played identical speech messages to the left and right ears in a dichotic listening paradigm but staggered in time so that the messages arrived at the two ears several seconds apart. She had participants "shadow" the speech coming in one ear; that is, the participant repeated back out loud the words coming in the attended ear. Treisman then brought the unattended message closer in time to the shadowed message and noted how far apart the messages were when the participant realized that the same message was being played to both ears. The result depended on whether the shadowed (attended) message was leading or lagging in time; if it was leading, participants recognized that the unattended message was the same when it occurred 5 seconds later. But when the shadowed message followed the unattended message, the two messages had to be brought within 1.5 seconds before participants realized that they were the same. Apparently, the full analysis of the attended message had the effect of tripling its survival time in short-term memory to enable a match to be made.

This result suggested to me that memory and attention are very closely interlinked. Not only the everyday observation that to remember something well you must pay attention to it, but the more precise idea that the durability of the encoded memory record might depend on how deeply analyzed the stimulus had been. Perhaps memory processing was essentially the same thing as processing for attention and perception.

This thought was followed by some back-of-the envelope sketches, some shared with my graduate students whose reactions were somewhat less than wildly enthusiastic. My student Michael Watkins, who went on to have an illustrious career at Princeton and Rice Universities, remembered one such occasion in the following terms (Watkins, 2001):

> A little more than three decades ago, a singular young researcher joined his students at lunch and mentioned that he had been thinking. His students harkened at once, for Fergus Craik is a modest man, not given to bluster. Craik reached for a scrap of paper and drew a horizontal line, from which dropped two vertical lines, one short and one long.
>
> "What's that, Gus?"
>
> "It seems to me," said he, "that memory for something depends on how deeply the something is processed or analyzed."
>
> "That's it, Gus??"
>
> "Well, that's the essence of it . . ."

To be fair, my London students *were* interested in this somewhat different perspective, but I moved to Toronto shortly after this time, so the initial empirical explorations of the levels-of-processing (LOP) ideas were carried out with other colleagues. I also wrote about these nascent ideas to Endel Tulving, who was then at Yale University. He was "cautiously encouraging," I would say, acknowledging that the LOP framework fitted some recent data quite well (e.g., Hyde and Jenkins, 1969), and also pointing out some shortcomings. These latter aspects included the point that the notion emphasizes storage with no clear link to retrieval processes, and also that the LOP idea appears to focus on the encoding of single items and does not address interdependencies among items, such as organization and mutual inhibition. He was quite correct on both points, I believe. However, as we talked and corresponded further, Tulving became progressively more enthusiastic about the ideas and contributed two crucial components to their development. The first, as related further in the next section, was his invitation to write up the ideas as a theoretical article for the *Journal of Verbal Learning and Verbal Behavior* (*JVLVB*), and the second was his agreement to collaborate on the empirical studies that were suggested by the LOP framework.

The Craik and Lockhart article

When I arrived in Toronto to take up a faculty position in the fall of 1971 I was delighted to find that my friend and colleague Bob Lockhart had been thinking of memory in much the same way as I had. We shared the view that remembering should be thought of as a set of encoding and retrieval processes, rather than as a series of stores. Clearly there were qualitatively different ways in which information could be represented in the cognitive system; for example, words could be represented as visual images, in terms of their phonological, articulatory, or lexical features, and also in terms of the meaning they conveyed, either as single items or as components of a sentence. But these different encoding and representational dimensions are not stages or stores; they are simply different aspects of representation. Lockhart and I also shared the view that "deeper" processing, in the sense of greater involvement of meaning and implication, was likely associated with longer-lasting memory records.

In early 1972 Endel Tulving was finishing his stint as Editor of *JVLVB*—in those days the top journal in the areas of memory and verbal learning. His original plan at that time was to have the last issue under his editorship as an all-invited issue; as it happened, this did not work out, but Bob Lockhart and I were the beneficiaries of Tulving's scheme as he invited us to write an article on the "levels" notions for the December issue of the journal. Tulving was working at Yale University at that time, and he wrote to me from there in January, 1972, with the following proposition:

> I am writing to you to ask you whether you would not wish to write a paper, not too short and not too long, in which you would extol the virtues of whatever grand system of thought, theory, or metaphysical speculations relevant to human memory, or to some other manifestation of Mind, you hold at the moment of writing. I had especially in mind your notions about levels of analysis in short-term memory, although you yourself may wish to do something else. I would publish the paper essentially as you would submit it, so you would not have to

> worry about fighting and haggling with the establishment who might normally resist your innovative ideas. The nature of the article would be primarily theoretical, and integrative, rather than a vehicle for presenting new experiment results. Just about the only catch here is that I would have to have a reasonably tidy and completely finished manuscript no later than June 1.

Lockhart and I accepted with alacrity of course, and got down to work pretty well immediately. Endel Tulving took a paternal interest in our progress and indeed, was immensely helpful in shaping the final published version. Bob Lockhart and I work well together, so writing was not too much of a chore. Our styles are somewhat different, however, with Lockhart taking a rather philosophical approach relative to Craik's more concrete and empirical approach. It is possible that these differences in emphasis yielded a rounder, and in some sense a "deeper," final version. One incident occurred during a summer evening writing session as we labored to meet the June 1 deadline (we failed as I remember!). Our colleague Ben Murdock came into our room and tossed a book on the table with some phrase like "You fellows may be interested in this!" before walking out grinning broadly. The book was Laird Cermak's recently published *Human Memory, Research and Theory* (1972) in which he lays out a very similar set of ideas to those that Lockhart and I were working on. So, levels were in the air in 1972 it seems. I did not know Cermak at the time, but I later met him and we became good friends. We jointly organized a conference on LOP, held in 1977, and this yielded a book of the proceedings (Cermak and Craik, 1979). Meanwhile, back in Toronto in 1972 Lockhart and I finally finished a draft that we and Tulving were happy with, so off it went to the publishers, with Bob Lockhart and I going through manic-depressive cycles—alternating between thinking we had come up with something quite useful, and thinking that the main message was trite and obvious—"meaningful things are remembered better." Put that way it hardly seemed like a major breakthrough!

In fact, the article by Craik and Lockhart (1972) made a number of suggestions on how to conceptualize human memory in cognitive terms, and, naturally enough, some have stood the test of time better than others. At the time of writing our main aim was to question the usefulness of the dominant "stores" model (the idea that memory could be understood in terms of various memory stores: sensory memories plus short-term and long-term memory) and instead suggest that the persistence in memory of a perceived event depended on its depth of analysis, where "deep" analysis referred to processing of meaning and implication. Following some perceptual theorists, principally Treisman (1964a, 1969), we endorsed the notion of a hierarchy of processing stages running from shallow sensory analyses through intermediate stages such as phonology to deeper semantic analysis. We did also suggest (p. 675) that after identification the processed event may undergo further processing by enrichment or elaboration by integration with past experience. One major point was our emphasis on the notion that the purpose of virtually all day-to-day processing is perceptual; at shallow levels to successfully navigate our environment, and at deeper levels to identify events and process their implications. Further, that these various sensory, perceptual, and conceptual analyses automatically yield a record of the analyses, and we may think of this record as the memory trace. Thus, importantly, deep perceptual and conceptual analyses are by themselves sufficient to form a long-lasting memory trace; *intention* to learn or memorize is not important; trace persistence is entirely a matter of the qualitative nature of the processing carried out—for whatever reason.

This last point was borne out strongly by studies involving incidental learning, in which participants are asked to process a series of words in a given way (e.g., judge the number of syllables each word contains or rate each word for pleasantness) and are then unexpectedly asked to recall or recognize the words. At the time of writing the Craik and Lockhart article, the literature (e.g., Hyde and Jenkins, 1969; Postman, 1964) confirmed the notions that later retention depended on the initial "orienting task," tasks involving greater degrees of semantic processing were associated with better memory performance, and intentional learning differed from incidental learning only to the extent that intentional learning induced participants to carry out different operations from those induced by the incidental task. One case in point is that intentional learning is typically associated with better free recall in young adults than the level following a semantic orienting task (Challis et al., 1996; Craik, 1977a), probably owing to the fact that intentional learning induces participants to carry out inter-item organizational processing in addition to processing each item; such organization is beneficial to free recall, in particular.

Perhaps the main contribution of the "levels" paper, however, was its emphasis on memory as a set of dynamic processes rather than as a set of structures. In line with the main theme of this book, encoding was conceptualized as the same processes underlying perception and comprehension. In agreement with the suggestions of a number of previous theorists described in Chapter 2 (notably Bartlett, 1932), we should think of *remembering* as an activity of mind and brain. Assuming that retrieval is also a matter of active processing, the question immediately arises as to the relation between the processes associated with encoding and retrieval. In later articles (e.g., Craik, 1983) I endorsed the notion that retrieval is essentially a matter of recapitulating the same processes (as nearly as possible) as those carried out at the time of encoding, and this point of view is explored further and substantiated in Chapter 5. However, in the Craik and Lockhart article we were not so thoroughgoing, and suggested simply that encoding processes gives rise to an encoded record of these processes—the memory trace. Clearly *something* must change in the brain in order for remembering to occur at a later time, but the notion of a set of "memory traces" each representing a specific encoded event does not seem to be the way to go. However, merely repeating the same encoding operations at the time of retrieval, as suggested by Paul Kolers (1973), brings its own problems—for example, how do we know we are *remembering* an event as opposed to simply perceiving and understanding it for the first time? These thorny questions are taken up again in Chapter 4.

The Craik and Lockhart article is sometimes cited as the article that questioned the validity of the distinction between short-term memory (STM) and long-term memory (LTM). Indeed, we questioned the validity of the "stores" concept but strongly maintained the distinction between "primary memory" and LTM, although in different terms. In our view primary memory was equivalent to recirculating information at a constant level of processing—typically a relatively shallow level. We commented that "in our view, such descriptions as 'continued attention to certain aspects of the stimulus,' 'keeping the items in consciousness,' 'holding the items in the rehearsal buffer,' and 'retention of the items in primary memory' all refer to the same concept of maintaining information at one level of processing" (Craik and Lockhart, 1972, p. 476). This notion of rehearsal being equivalent to the recirculation of information at a given level was also linked to the overall view that retention is a function of the depth of processing achieved, by the suggestion that maintenance of information at a constant level would not enhance subsequent memory performance. In order for rehearsal to improve memory it is necessary for the rehearsal processes to engage deeper levels. This contrast was given the rather unimaginative label of "Type I and Type II processing." Better terms—maintenance and elaborative processing—were later suggested (Craik and Watkins, 1973; Woodward et al., 1973), and these terms are now in general use. So Craik and Lockhart maintained the distinction between STM and LTM, but with STM thought of as primary memory (PM)—those items held by attentional processing in conscious awareness. PM, in our terms, had a limited capacity, but the limit was in terms of the limited amount of attentional resources available to process aspect of words (typically phonology or articulation) rather than some structural limit. We also suggested that the "coding characteristic" of PM was not fixed but was flexible—depending on the aspect of held information being attended to—phonology, articulation, imagery, semantic, etc. That is, "the processor itself is neutral with regard to coding characteristics; the observed PM code will depend on the processing modality within which the processor is operating" (Craik and Lockhart, 1972, p. 676). Further thoughts on PM, and on how primary memory and working memory are related, are deferred until Chapter 6.

A troubling absence from the Craik and Lockhart article is the lack of an objective index of depth or processing. In the absence of such an independent index it is all too easy to claim that well-remembered items must therefore have been deeply processed. That is, the scientific logic is "circular" as our critics (e.g., Baddeley, 1978; Eysenck, 1978; Nelson, 1977) were quick to point out! We have countered this criticism in various ways. First, although the dimension of depth has been described in intuitive terms it seems that researchers' intuitions do converge (Seamon and Virostek, 1978; Anderson and Reder, 1979). For example, Anderson and Reder conducted an informal study (n = 2) in which the authors independently rated

11 tasks suggested by Nelson (1977); the resulting correlation between their rank order ratings was R = 0.974. So it is certainly possible to define depth plausibly and then examine the results. Given that such findings have included recognition memory scores ranging from 15% to 81% depending only on the type of processing carried out at encoding (Craik and Tulving, 1975, Experiment 2) it does seem that something of interest to memory theorists is going on! One possible index is initial decision time (response latency to each orienting task question) and that does yield an impressively regular relation between initial decision time and later recognition memory (Figure 1.3). As the figure shows, however, different functions were observed for words that were positive answers to the orienting question (e.g., "Related to the church?" PRIEST), as opposed to negative answers (e.g., "A piece of furniture?" TIGER). So it seems clear that other factors, as well as depth, are at play here.

Two other responses to the circularity question have been considered (e.g., by Lockhart and Craik, 1978, 1990) and will come up again in this book. The first is the point that the Craik and Lockhart proposal was explicitly described as a

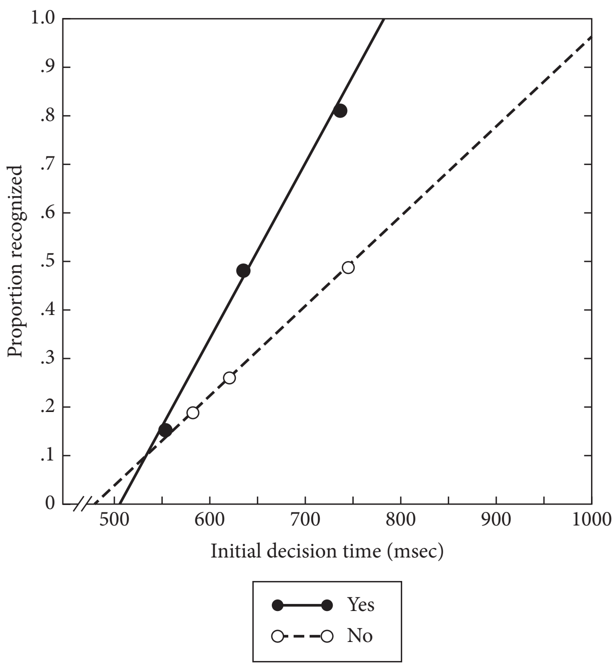

Fig. 1.3. Proportions recognized as a function of initial decision time to "yes" and "no" questions (Craik and Tulving, 1975, Experiment 2).

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"framework" for memory research as opposed to a semi-formal model. As we said at the time, "Our approach does not constitute a theory of memory. Rather, it provides a conceptual framework—a set of orienting attitudes—within which memory research might proceed" (Craik and Lockhart, 1972, p. 681). After almost 50 years it seems reasonable to claim that our framework has, indeed, stimulated interest and spawned a wide variety of studies in the LOP tradition. The second response is more empirical and may strike the reader as somewhat less evasive! This is the notion that measures from neuroimaging may provide the missing index. Given the very large differences in memory following processing to different depths, it seems certain that these behavioral differences must have brain correlates, both qualitative and quantitative in nature. Subsequent studies (e.g., Kapur et al., 1994; Otten et al., 2001) provided evidence in favor of this point.

Empirical studies of levels of processing

When I started work at the Erindale Campus of the University of Toronto in the fall of 1971 I immediately set out to gather experimental evidence on the idea that retention levels depended on the initial depth of processing. I took the notion of "levels" rather literally and so designed an experiment in which single words were each preceded by an orienting question and then exposed for exactly 200 msec in a tachistoscope (a device, common in these far-off days, in which stimuli could be shown for specified brief periods). The setup also allowed for response latency to be measured—from the onset of the target word to the participant's response. Participants were told that the study was concerned with how rapidly they could make various kinds of decisions about words; they were not informed about the later memory test. The idea behind the 200 msec exposure (later questioned by Endel Tulving) was that processing would stop at the level dictated by the orienting question and if the word was no longer visible this would decrease the chances that processing might slip to deeper levels. Before each word was presented participants were asked one of five different questions about the upcoming stimulus:

1. Is there a word present?
2. Is the word in capital letters/lower case?
3. Does the word rhyme with ______________?
4. Is the word a member of the following category ______________?
5. Does the word fit into the following sentence ________________?

Eight questions were asked at each level, with half of the questions associated with a "*yes*" response. After all 40 questions had been answered, participants were given a sheet with 80 words, the original 40 plus 40 similar lure items; the task was to check all words they recognized from the first phase. Fuller details are given in Craik and Tulving (1975, Experiment 1).

The study was run as an undergraduate project by Karl Egner, and I can still remember my excitement, mixed with some incredulity, when Karl showed me the results. The decision latencies and proportions recognized are shown in Table 1.1.

Latencies increased steadily for both yes and no responses as a function of increasing depth with no obvious systematic differences between the response types, and an analysis of variance (ANOVA) confirmed a large effect of depth on latency but no effect of *yes* vs. *no*. The proportions recognized also increased systematically with depth, but now *no* decisions were associated with lower recognition scores than *yes* decisions. In this case an ANOVA (after arc sine transformation) on levels 2-5 revealed strong effects of both depth and response type, and also a significant interaction between the variables; the superiority associated with *yes* responses was greatest at levels 3 and 4, although there is an obvious ceiling effect for *yes* responses at level 5. The really surprising thing about these results was the point that whereas response latency increased by only 200 msec between levels 2 and 5, the proportions recognized increased by a factor of more than 5—from a mean of 0.16 to a mean of 0.90, simply as a function of the processing carried out.

These initial experiments are described in detail in Craik and Tulving (1975), but one further study will be outlined here to illustrate the classic "levels" effect. In this case only three levels of encoding were used: Questions about typescript (upper or lower case); rhyme questions; and sentence questions (in which participants were given a sentence frame with one word missing). Participants answered

Table 1.1. Initial decision latencies and recognition performance for words as a function of orienting task (Craik and Tulving, 1975, Experiment 1).

Response type	**Level of processing**				
	1	**2**	**3**	**4**	**5**
	Response latency (msec)				
Yes	591	614	689	711	746
No	590	625	678	716	832
	Proportion recognized				
Yes	.22	.18	.78	.93	.96
No		.14	.36	.63	.83

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60 questions, 10 positive and 10 negative trials at each of the three levels. They were then given a recognition list with the 60 words plus 120 distractors (to avoid ceiling effects) and asked to check the words from the first phase. The results for response latency and proportions recognized are shown in Figure 1.4. Response latencies rose from about 550 msec to 730 msec from case to sentence judgments with little difference between yes and no answers. Recognition levels for *yes* responses rose from 15% for case decisions to 81% for sentence decisions—again a fivefold increase in performance. Recognition levels for *no* decisions also rose, but less sharply, from 19% to 49%. An ANOVA on the recognition data showed strong effects of levels, of response type, and an interaction between the variables.

The lower recognition levels associated with *no* responses was an unexpected result. After some debate, Tulving and I decided that in the case of positive rhyme and sentence decisions the target word would more easily be enriched by the question. For example, the sentence frame "The boy bought a _____ at the store" could form an integrated image with the word BALL but much less so for the word

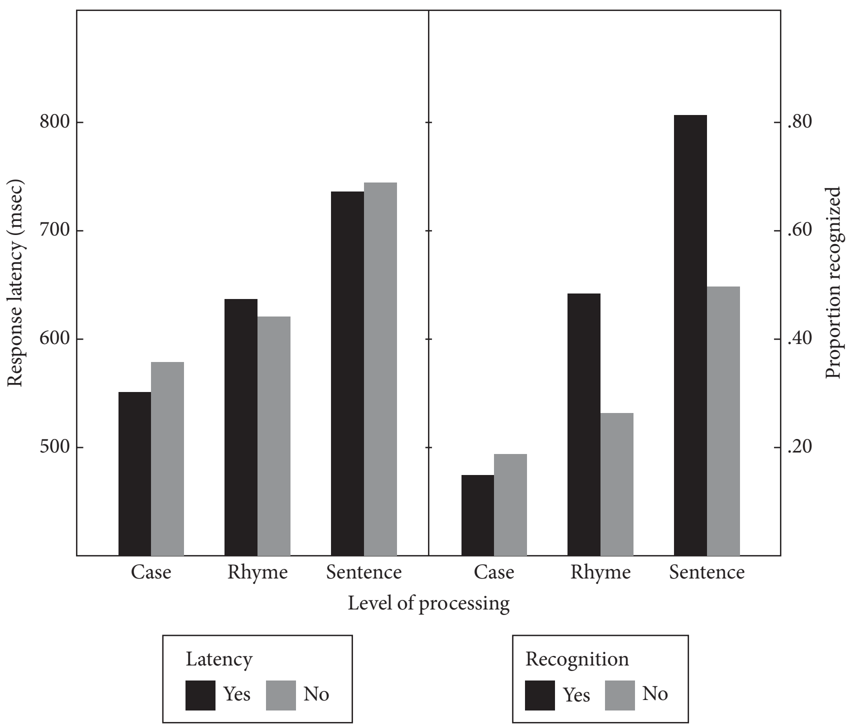

Fig. 1.4 Initial decision latency and recognition memory performance as a function of orienting task (Craik and Tulving, 1975, Experiment 2).

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CLOUD. We therefore concluded that both depth and elaboration played a role in the final memorability of the processed words. In a sense, the equivalent response latencies for *yes* and *no* responses at each level suggested that depth of processing was equivalent for the two response types, so some other dimension clearly played a role. The different relations between decision latency and subsequent recognition for *yes* and *no* responses shown in Figure 1.3 (also from Craik and Tulving, 1975, Experiment 2) make the same point.

The other experiments in the Craik and Tulving article made a variety of points to flesh out the basic pattern of results shown in Figure 1.4. Experiment 4 showed that the same pattern was obtained when participants were told in advance that a memory test would follow the first phase—so the careful 200 msec exposure seemed less necessary. One major point to clear up concerned the relation between initial decision time and subsequent memory levels. The initial studies did, after all, show clearly that deeper processing took longer to accomplish, and some critics pointed to the well-established positive relation between time spent learning verbal materials and subsequent retention level (e.g., the "total time hypothesis" of Cooper and Pantle, 1967) saying that the "levels" effect was simply a further illustration of this general rule. My informal reaction to this criticism was to say that our result was therefore splendid news for the educational system—let the kids study for one-fifth of a second longer and you will quadruple the amount learned! A more sober response, however, was to design an experiment pitting a shallow but difficult orienting task against an easy semantic task, with the expectation that the shallow task would take longer to accomplish but would nevertheless be less well retained than words processed in terms of the easier but deeper task. For the shallow task, we asked participants whether the upcoming word would fit the following pattern of consonants (C) and vowels (V). So the word TABLE could be represented as CVCCV, the word UNCLE as VCCCV, and so on. The deeper semantic task was the sentence-frame task used in previous studies, for example, would the word fit the following sentence frame: "Near her bed she kept a ____ " (CLOCK). Again, half of the questions were associated with *yes* responses and half with *no* responses. The basic result for *yes* responses was that processing times for shallow and deep tasks were 1.70 s and 0.83 seconds, respectively, and the proportions recognized were 0.57 and 0.82, respectively. Similar results were obtained for *no* responses (Craik and Tulving, 1975, Experiment 5). The experiment thus showed that the good memory performance following deep encoding depended on the qualitative nature of the processing and *not* simply on the time taken to perform the orienting task.

Figure 1.4 shows that negative responses to orienting questions are associated with lower levels of subsequent memory performance than positive responses, especially at deeper levels of encoding. Our suggestion (mentioned earlier) was that positive responses could be better integrated with (or elaborated by) the orienting question than could negative responses, but we wished to illustrate this more directly. Our suggestion was that if specific orienting questions could be devised that would lead to equivalent elaboration for positive and negative decisions, the subsequent retention levels should also be equivalent. Experiment 6 in the Craik and Tulving series thus asked questions about a variety of descriptive dimensions—for example, size, length, weight, value, etc. The questions took the general form of asking whether the upcoming word was larger (or longer, heavier, more valuable, etc.) than some specified referent. For example, "Taller than a man?" (STEEPLE-yes; CHILD-no), "More valuable than $10?" (JEWEL-yes, BUTTON-no). We argued that in such cases negative responses would be elaborated just as much by the orienting question as would positive responses. In this experiment memory was measured by recall, and at the time of retrieval participants were reminded of the various questions asked. The result was that words associated with a positive response were recalled with a probability of 0.36, while words associated with a negative response were recalled with a probability of 0.39. These probabilities did not differ statistically. The experiment thus gave some backing to the idea that retention levels in our experiments reflect both depth and elaboration.

One final experiment from the 10 reported by Craik and Tulving (1975) will be described here. My co-author had formed a growing suspicion that the experimental conditions dictated by his senior author in most previous experiments (e.g., incidental learning, 200 msec exposure time for words) reflected superstitious behavior rather than essential features of the paradigm. Accordingly, he elected to run a version of the experiment in which the participants were students in a class studying memory. They were informed beforehand that memory would be tested for the words seen, and the words were presented for 1 second each with a 5-second inter-word interval. On each trial participants were asked a case question (Upper- or lowercase?), a rhyme question, or a question about the word's category (e.g., "A kind of fruit?"). Participants in this classroom demonstration all saw the same sequence of words, but each was asked a different question about the upcoming word (see Craik and Tulving, 1975, Experiment 9).

The results are shown in the top half of Table 1.2; they clearly follow the pattern illustrated by Figure 1.4 very closely. In fact, Endel Tulving phoned me from his bridge club to tell me the results, and I have a flashbulb memory of the event. I was amazed! And slightly skeptical. Accordingly, we ran a further group of student participants under the same conditions and their results are shown in the bottom half of Table 1.2. The proportions recognized were somewhat higher in this replication, but the pattern is identical. The immediate question they raise is: If participants had 6 seconds to process each word in an intentional learning paradigm, why did they not simply process the "shallow" words deeper and end up with equivalent recollection of all types of word? I think the answer lies more with the elaboration conferred by each orienting question than with "depth" as such. That is, when presented with a word in the recognition test the participant remembers (in some cases at least) that the initial question concerned rhyme, a specific category, or whatever, and

Table 1.2. Proportions of words recognized as a function of initial orienting task in two replications of Experiment 9 from Craik and Tulving (1975).

Response type	Case	Rhyme	Category
	1st study		
Yes	.23	.59	.81
No	.28	.33	.62
	2nd study		
Yes	.42	.65	.90
No	.37	.50	.65

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this increases the person's confidence and accuracy in his or her response. In fact, we have shown over the years many instances in which university students recognize more words after an incidental learning encoding phase involving semantic questions than they do after an intentional learning phase in which they are simply instructed to "learn these words for a subsequent memory test." Their learning systems are clearly capable of learning material better than they do using their own preferred strategies. This phenomenon is well known in children, where it is referred to as a "production deficiency"—children are not yet capable of producing efficient learning strategies on their own, despite having minds that are *capable* of performing at a higher level. It is more surprising to find the effect persisting in university students, however. One exception to this finding is that *recall* (as opposed to recognition) is typically better under intentional learning conditions than following incidental semantic learning. As mentioned earlier, this may be attributable to the better inter-word *organizational* processing undertaken by sophisticated learners (see the study by Challis et al., 1996, described in Chapter 4 for an example).

Criticisms and rebuttals

It has suited my particular nature, over the years, to treat theory as an orienting framework whose function is to suggest experiments that will stabilize and strengthen the framework, rather than confirm or disconfirm some specific theoretical proposition. It seems to me that cognitive psychology is still in its descriptive, pretheoretical phase in terms of scientific evolution, and that highly specific theorizing may thus be premature. As one example, the Atkinson and Shiffrin (1968) model of memory has been tremendously helpful and influential over the past 50 years, but to my mind it is their overall framework that has guided (and been modified by) empirical work, not the specific mathematical model of transfer from short-term store to long-term store. The Craik and Lockhart (1972) paper was explicitly set out as a *framework* (thanks very largely to my wise colleague Bob Lockhart!), and still has some utility in that respect.

The ideas and empirical findings contained in the articles by Craik and Lockhart (1972) and Craik and Tulving (1975) were generally well received by our colleagues in cognitive psychology, many of whom shared our misgivings about the current memory stores model. Nevertheless, and quite properly, the LOP notions were criticized in a number of publications. Several of these critics were my British compatriots (Alan Baddeley, Michael Eysenck, and John Morton), which stung me somewhat at the time as I had conceived of the "levels" notions being very much in the tradition of Bartlett, Broadbent, and Treisman. Interestingly, Canadian and American colleagues were generally more accepting. But the main usefulness of the critical articles was to force our attention on the weaker aspects of our ideas and modify them accordingly.

Eysenck (1978) correctly pointed out the problems associated with the absence of an independent index of depth; it is all too easy to conclude that if an event is well remembered it must therefore have been processed deeply. Thomas Nelson (1977) was even more severe on the same topic, concluding that "until such falsification becomes possible, statements about such-and-such a result being in accord with the deeper-processing principle are scientifically meaningless" (Nelson, 1977, p. 165). In our mild reply to such criticisms we acknowledged the problem of circularity but argued that in our current uncertainty concerning how to conceptualize memory "an idea is likely to be helpful to the extent that it brings a measure of coherence to the data and provides firm guidance on the kinds of relationships that are important to study, and on the kind of data that should be collected" (Lockhart and Craik, 1978, p. 172). I cited some other counterarguments earlier in this chapter, holding out the hope that measures of brain function may provide an index of depth.

In his critical review of the LOP ideas, Baddeley (1978) questioned the reasonableness of our rather literal account of depth of processing as a single linear sequence. We agreed with Baddeley on this point, and, indeed, had already suggested (Lockhart et al., 1976) that it was more likely that the cognitive system achieves a particular pattern of depth and elaboration after complex interactions between top-down and bottom-up processes. What was more important to our position was not the temporal sequence of such interactions but the pattern of analyses finally achieved (Lockhart and Craik, 1990).

One empirical issue that came under fire was the notion that maintenance processing at some intermediate level "in primary memory" did nothing to enhance subsequent memory. Nelson (1977) showed in a series of experiments that if a word is repeated in an incidental learning paradigm in which participants make phonemic decisions about a series of words, subsequent memory performance is, in fact, increased by repetition. However, this interpretation of "repetition" in which the same word is repeated either immediately or after several intervening words is rather different from "maintenance rehearsal" in which participants continuously repeat 2–3 words in terms of their phonological or articulatory features. An experiment of the latter type, in which participants either recalled the last four words in a free recall list immediately or after an unfilled 20-second interval in which they were instructed to rehearse the last four words several times before recall, was reported by Craik and Watkins (1973). Twelve lists were presented, six with immediate recall and six with rehearsal followed by delayed recall. After presentation and recall of all 12 lists, participants were given a "final free recall" test in which they were asked to recall as many words as possible from all 12 lists. The major result of interest was that final recall of the original last four words was equivalent for immediate and delayed lists, despite the fact that the final words in delayed lists had been rehearsed an average of six times more than final words in immediate lists. That is, the continued maintenance rehearsal of final words in the delayed condition prior to the first recall test had no beneficial effect on recall on the second (final) recall test.

It seems, then, that repetition of an item with a phonemic question (as in Nelson, 1977) *is* beneficial to later recall, whereas repetition of items in a continuous rehearsal loop (as in Craik and Watkins, 1973) is not. The latter result was also reported by Jacoby and Bartz (1972) and by Woodward et al. (1973). In fact, there was a period in the early 1970s that experimental work in the Bjork and Craik laboratories was so parallel that when Bob Bjork and I met up at conferences we used to ask humorously "So what have I been doing in my lab recently?" Interestingly, a later review by Greene (1987) concluded that pure maintenance rehearsal does sometimes result in an increase in subsequent recall, although it *always* results in an increase in recognition memory. This difference between recall and recognition suggests that maintenance rehearsal may, in fact, increase "*intra*-item integration" but not "*inter*-item elaboration" (Mandler, 1979). That is, maintenance rehearsal may increase the strength or coherence of a word's representation but not increase organization *among* list items. Further, there is good evidence that whereas free recall is mainly sensitive to manipulations that increase organization, recognition memory is sensitive to increases in strength and coherence of individual items. In this respect it would be of interest to check whether the benefit to recognition associated with maintenance processing reflects "know" rather than "remember" retrieval processing in the sense described by Gardiner and Richardson-Klavehn

(2000). The general issue of maintenance processing and its effects is discussed further by Lockhart and Craik (1990).

Another influential critical article was published by Morris et al. (1977) under the general rubric of transfer-appropriate processing (TAP). The notion of TAP has a strong family resemblance to Tulving's encoding specificity concept and Kolers' repetition of operations—namely that remembering is optimal when retrieval operations match encoding operations as closely as possible. This central truth about memory is discussed at greater length in the chapters on encoding-retrieval interactions. Morris et al. (1977) showed that when the retrieval test was one of rhyme recognition ("Did the list contain a word that rhymed with TRAIN?"), rhyme encoding was superior to semantic encoding—in line with the TAP principle. They therefore concluded that it is not possible to say that deep semantic encoding is always superior; optimal encoding will depend entirely on retrieval circumstances—a relative rather than an absolute principle. This article rightly received a lot of attention and was even regarded by some (e.g., Rosenzweig, 1994) as the paper that sounded the death knell of LOP: "This view includes encoding at the 'deep' semantic level for some tests, but other kinds of encoding for other kinds of tests, so transfer-appropriate processing is a much broader and inclusive formulation than is levels of processing" (Rosenzweig, 1994, p. 3). But when one looks at the data presented by Morris et al. (1977) it is immediately clear that all transfer-appropriate combinations are not equivalent. In their data the mean value for "rhyme-yes" processing followed by a rhyme recognition test was 0.40 (averaged over Experiments 1 and 2), whereas the mean value of "semantic-yes" encodings followed by a standard (semantic) recognition test was 0.68. The reasonable conclusion thus seems to be that a full understanding of the cognitive processes that make for good remembering requires both principles of good encoding (e.g., LOP) and principles relating encoding to retrieval (e.g., TAP). This theme of encoding-retrieval interactions is taken up again in Chapters 4 and 5.

One of the best critical articles addressing the LOP framework was written by Alan Baddeley (1978). A number of features of the LOP framework troubled him, and he obviously felt strongly that the field should not be misled by false prophets thinly disguised as Craik and Lockhart! Along with others, Baddeley pointed out the circularity inherent in the levels formulation and the absence of an independent index of depth. A further major criticism concerned the wisdom of trying to understand memory in terms of general functional principles. Baddeley's own approach was to propose specific cognitive mechanisms that could be experimentally refined and ultimately identified with neural processes and structures. These are all very reasonable points, many of which we agreed with (for a discussion, see Lockhart and Craik, 1990). Baddeley also pointed to recent evidence that sensory information can be extremely long-lasting under some circumstances (e.g., Kolers, 1976) and that, according to LOP principles, this should not happen. My answer to this point is that the long-lasting effects of sensory information are typically seen in implicit memory situations, but nonetheless it must be conceded that the effects of shallow processing can be long-lasting under certain conditions; the information is not inevitably lost quickly as was suggested in the original LOP article. Finally, Baddeley cited some evidence to show that LOP manipulations had little or no effect on pictures. He therefore concluded that the LOP ideas were quite limited in their scope, with little or no universal application. In later work I had also noted the limited effects of LOP on picture stimuli (Craik, 1983) but took the view that pictures are inherently meaningful and, in a sense, "drive" a deep encoding regardless of the orienting task or other contextual variable. It is gratifying to note that many years later Alan Baddeley and Graham Hitch returned to the question of levels and pictures, finding that pictures *are* sensitive to depth manipulations under some conditions. They go on to make useful modifications to the LOP framework in light of their new findings (Baddeley and Hitch, 2017). This work is described later in the book.

I will recount one further anecdote in this section of criticisms as it gave rise to much pondering on my part. In the early summer of 1973 I went through to Montreal to visit my friend Morris Moscovitch who was spending the year in Brenda Milner's laboratory at the Montreal Neurological Institute. While I was talking to Morris in his office, Brenda popped her head round the door to say hello and apologized that she could not stay and chat as she was already late for a meeting. "However," she said, "my amnesic patients have no trouble perceiving and comprehending events—they are clearly processing at a deep level—yet they don't remember things; how does that fit with your theory . . . ?" "Sorry, can't stay . . . " she added, leaving me to worry (for the next few decades!) about the undeniable problem that she had raised. Given the work with orienting tasks, I had been very happy with the notion that deep processing was sufficient for good later memory, but Milner's remarks about amnesics made it necessary to concede that some form of consolidation is also necessary, and that damage to the hippocampus (as with amnesic patients) impairs this process. Further speculations along this line concern the memory impairments associated with normal aging—are they attributable to a failure to encode so deeply (or elaborately) or to some functional inefficiency of the hippocampus and consolidation? And, finally, what about transient memory impairments associated for example with alcoholic intoxication, fatigue or division of attention? Do these eminently reversible conditions reflect cognitive processing failures or temporary reductions in hippocampal function? We have made some efforts over the years to address these problems (e.g., Craik and Kester, 2000, see Chapter 4), but without coming to a firm conclusion. The archetypical case of this sort—the patient H.M. who had no problems with perception or comprehension, but essentially no episodic memory (Corkin, 2013; Scoville and Milner, 1957)—is discussed in the context of a new theory of memory organization proposed by Murray, Wise, and Graham (2017). These notions are described and assessed in the final chapters of this book.

2
Processing Views of Remembering
A Brief Historical Survey

One major theme running through this work is the idea that we should regard human memory as an activity of mind rather than as a structural entity—as the *processes of remembering* rather than as a set of "things in the head." This is hardly an original thought; in more general terms the debate on whether to view mind as a set of activities or as a collection of structural representations of the external world has been going on for centuries at least. One early, and very influential, proponent of the activity perspective is Gottfried Leibniz (1646–1716). In his compendious *History of Experimental Psychology*, Edwin Boring describes Leibniz as heading "a tradition of activity-psychology, which has persisted mostly in Germany and Austria, but also in England" (Boring, 1950, p. 166). He goes on to state that, for Leibniz, the most obvious thing about mind is its activity, which must therefore be the starting point for all theories of psychology. Activity in Leibniz's scheme is "most like perception" and is the correlate of consciousness. In turn, consciousness is not all-or-none but shows *degrees of consciousness*, (Boring, 1950, pp. 166–7). So, it seems that for Leibniz the experiences of perceiving and of conscious awareness depend on mental activity, and I find this perspective very congenial. However, Boring goes on to say that in Leibniz's view "consciousness does not explain or create matter. Consciousness is matter, and matter consciousness" (Boring, 1950, p. 167), and I confess that this goes too far for me. To me, mental activity is, indeed, the correlate of perceiving and of consciousness in general, but the activity takes place in the substantive structures of the nervous system. As I elaborate later, such cognitive constructs as perceiving, remembering, and thinking thus depend on both the activities and structures of the nervous system but with the difference that only the *activities* are proximally related to psychological experience. Specific perceptual and memory experiences may well entail activity in specific neural regions or networks, but the relations between such neural structures and cognitive experiences are essentially mapping relations. That is, specific mental experiences may be associated with specific brain structures, but it is the activity within these structures that is the strong correlate of the experience, albeit at a different level of explanation.

The "Act Psychologists" (e.g., Brentano and Stumpf) form another important group of early psychologists who endorsed the notion of mind as activity. In Boring's (1950) account of the loosely affiliated group, Franz Brentano (1838–1917)

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stands out as the major figure, who also serves as an interesting contrast to the emerging dominance of Wilhelm Wundt as the founder of experimental psychology. Brentano's position is described by Boring in the following way: "When one sees a color, the color itself is not mental. It is the seeing, the act, that is mental. There is, however, no meaning to *seeing* unless something is seen. The act always implies an object, refers to a content" (Boring, 1950, p. 360). In Brentano's scheme, the contents belonged to the physical world, outside of psychology, whereas Wundt and his followers treated sensory data as psychological. Wundt's perspective thus embraced physiology as the intermediary between the physical and mental worlds, and encouraged an experimental approach to the problems of "psychophysics." Brentano and his followers described their approach as "empirical," but their evidence was based more on everyday observation than on laboratory experimentation. This contrast between the philosophies of acts (Brentano) and contents (Wundt) gave rise to major debates in late-nineteenth- and early-twentieth-century psychology, with the act school leading to the Gestalt psychologists and the content school leading to the mainstream American experimental psychology of the mid-twentieth century.

William James (1890)

William James is one of my academic heroes (he is *everyone's* hero I suppose!), so I looked eagerly in his great *Principles of Psychology* (James, 1890) for signs of enlightenment in the sense that he would strongly endorse the notion of remembering as an activity of mind. The evidence is there, although it is somewhat indirect. One aspect is James' insistence on the close connection between memory and thinking. He makes the point (p. 663) that memory improvements will not come through any alteration of the underlying physiological mechanism; he takes that as fixed for a particular person. Rather, *thinking* about the event and relating it to existing knowledge will be associated with better memory. James also insists that repetition of an event is not by itself sufficient to remember the original; something else is required. That further thing is that present experiences invoke similar experiences from the past, so that the present experience contains not only current perception, but also aspects of past experiences, especially those involving feelings of self—that is, awareness that the current event occurred previously in *my* past (see also Hintzman, 2011, Chapter 10, for a similar view).

James then invokes brain representations and connecting pathways to suggest how this may happen. He suggests that if N is the neural representation of some past event, and O represents the context in which N occurred (the date, surroundings, presence of self, etc.) there is a neural pathway connecting N and O such that if N is reactivated it may also reactivate O. If this happens, the person will experience the memory represented by N plus O. He also proposes that some present thought or fact M may activate N through similarity but that this by itself would not give rise to a memory of the N event. For remembering to occur, N must activate O, representation of the prior *context*, including the presence of self. James goes on to say that the physiological existence of pathways linking M to N and N to O is a correlate of *retention*—the *potential* to remember but not remembering itself: "the existence of the paths M-N and N-O will be the fact indicated by the phrase 'retention of the event N in memory,' and the excitement of the brain along these paths will be the condition of the event N's actual recall" (p. 655).

James goes on to stress that retention

> is not a fact of the mental life at all. It is a purely physical phenomenon, a morphological feature, the presence of these "paths," namely, in the finest recesses of the brain's tissue. The recall or recollection, on the other hand, is a *psycho-physical* phenomenon, with both a body and a mental side. The bodily side is the functional excitement of the tracts and paths in question; the mental side is the conscious vision of the past occurrence, and the belief that we experienced it before (p. 655).

This statement is echoed in my own suggestion (Chapter 3) that the three classical phases of memory—encoding, storage, and retrieval—do not exist on the same level of explanation; only encoding and retrieval are cognitive processes; storage clearly exists, but at the level of neurophysiology.

James' analysis also prefigures the current distinction between familiarity and recollection (e.g., Jacoby and Dallas, 1981; Wagner and Gabrieli, 1998). If we bend his proposals slightly and allow that the evocation of M-N by itself can give rise to some disconnected feeling that we somehow know the event, but that it takes the complete evocation of M-N-O to give a complete feeling of re-experiencing the event, then his analysis sounds quite modern. In fact, the whole chapter on memory might well have served as a blueprint for experimental cognitive psychology starting around 1960! But my main takeaway point here is that James (1890) can very reasonably be included in the pantheon of former theorists who regarded remembering as an activity of mind and brain.

Bartlett and remembering

In this short review of philosophers and psychologists who have written about human memory as dynamic mental activity as opposed to a structural entity, pride of place must go to Sir Frederic Bartlett (1886–1969). I met him once, at a summer garden party in the grounds of the Applied Psychology Unit in Cambridge when he was quite elderly and I was a star-struck junior lecturer at the University of London. I remember a tall upright figure, quiet and courteous, a prototypical

Cambridge don and English gentleman. I remember nothing of our conversation if any, but suspect that I mumbled some banalities and moved on quickly to the white wine and strawberries.

Bartlett's great work is, of course, *Remembering: A Study in Experimental and Social Psychology*. In it he sets the scene immediately in the Preface by stating that "some widely held views have to be completely discarded, and none more completely than that which treats recall as the re-excitement in some way of fixed and changeless 'traces' " (Bartlett, 1932, vi). For Bartlett, "remembering" was essentially a reconstructive act in which recollection of the previous event was strongly colored by the person's acquired knowledge, attitudes, and beliefs. It is in this sense that Bartlett's work is a study in social, as well as experimental, psychology. In his account, all incoming experiences of a given kind go together to build up an active "organized setting" or schema particular to a mode of input or to a topic in the person's knowledge base. These schemas are constantly modified by further relevant inputs, and, in turn, help both to interpret new inputs and to reconstruct recollections of previous events. In this way attending, perceiving, remembering, and thinking are all intimately related in the cognitive system; schemas are built up and modified by attending and perceiving, and are, in turn, used to further understanding, remembering, imagining, and thinking.

Bartlett (1932, p. 188) also points out that the same sensory patterns can give rise to a great diversity of responses, both between individuals and in the same individual on different occasions. He therefore suggests that perception depends first on the sensory pattern, which provides the physiological basis for perceiving, but also on "another factor which constructs the sensory pattern into something having a significance which goes beyond its immediate sensory character." Bartlett equates this second factor with the function "effort after meaning"—presumably a product of the interaction between the sensory input and relevant schemas. He also makes it clear that, in his view, remembering depends on this second factor.

Remembering contains a number of other ideas that resonate strongly with readers some 90 years on. One is the suggestion "that the *differentia* of recognition and recall are given, at least partially, in the mode or conditions of the prior perception" (Bartlett, 1932, p. 188). The notion that memory performance depends strongly on the qualitative nature of the original perceptual encoding is of course the keystone of the levels of processing (LOP) account presented in Chapter 1. A second relevant quote is: "In all cases recognising is rendered possible by the carrying over of orientation, or attitude, from the original presentation to the re-presentation" (Bartlett, 1932, p. 193). This suggestion has a clear affinity to modern ideas of transfer-appropriate processing and encoding specificity (e.g., Morris et al., 1977; Roediger et al., 1989; Tulving and Thomson, 1973). As a third example, Bartlett concedes that schemas (or "schemata") will be largely configured to reflect recent experiences, but "to break away from this the schema must become, not merely something that works the organism, but something with which the organism can work … So the organism discovers how to turn round upon its own schemata, or, in other words, it becomes conscious" (Bartlett, 1932, p. 208). So schemas can be used both reactively to interpret inputs and in reconstructive remembering, and also proactively to determine appropriate courses of action. The notion of "working with memory" has also been proposed by Moscovitch (1994). In general, it is clear that Bartlett's ideas and clever demonstrations are forerunners not only to the concepts of LOP and other memory constructs, but also to modern cognitive psychology as a whole.

Activity theory in Soviet psychology

Another major precursor of the LOP approach to remembering is the Russian work on activity theory. The notion of "activity" here is not quite the same as that of mental acts or mental processes. Rather, "activity" in the sense used by various Russian theorists in the Soviet era and beyond is the idea that mental functions have their genesis in active interactions between the individual and his or her physical/social/cultural environment. Thus, Lev Vygotsky has written that:

> Every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first, *between* people (*interpsychological*), and then *inside* the child (*intrapsychological*). This applies equally to voluntary attention, to logical memory, and to the formation of concepts. All the higher functions originate as actual relations between human individuals (1978, p. 57).

In the same vein, Wertsch (1991) commented that Vygotsky viewed mental functioning as a kind of action; not as attributes of the individual, but as functions that may be carried out inter-mentally or intra-mentally.

This emphasis on including the external social, cultural, and physical worlds in the analysis and understanding of cognitive processes has been echoed more recently in Western psychology. The same emphasis is present in such topics as socially shared cognition (e.g., Resnick et al., 1991), socially distributed cognition (e.g., Hutchins, 1995), and collective memory (e.g., Middleton, 1987). The last 25 years has also seen the growth in output and influence of the "embodied cognition" movement (see, e.g., Clark, 1999; Varela et al., 1991; Wilson, 2002). As I understand it, this approach argues that all aspects of cognition are shaped by aspects of the body, and by the body's interactions with the external world. Thus, for example, perception is not a passive receptive process, but is essentially for the shaping and sharpening of appropriate action back into the environment. In turn, the degree of success of the action will tend to modify perception so that the organism is more perfectly adapted to its environmental surroundings. I have bought into this set of ideas by incorporating the notion of "environmental support" into my views on memory and aging (Craik, 1983, 1986), and these notions are more fully explored later.

The concept of activity in Soviet psychology is described and analyzed very fully in an excellent book written and edited by James Wertsch (1981). Following Vygotsky's lead, cognitive processes are viewed as having their origin in interactions with the external physical and social environment; it also follows that a full understanding of these processes can come only through a developmental analysis of how the processes have evolved to their present state through these interactions over the years. Once the interactions with external social, physical, and cultural features have been internalized by a person, they then act as mediating devices that play a major part in formulating further socially appropriate goal-directed actions back into the person's social and cultural environment. In this sense the Russian cognitive theorists take a similar view to such American thinkers as Robert Woodworth and Edward Tolman, who rejected a strict stimulus-response (S-R) analysis of behavior in favor of a stimulus-organism-response (S-O-R) analysis in which the organism's innate tendencies—in conjunction with previous learning—modify the responses produced to specific stimuli. This mediation formulation also allows motivational factors to play a role in the activity shown by an individual. As described by A. N. Leont'ev (1972; translated by Wertsch, 1981), the individual's past experiences and interactions with the cultural environment enable him or her to form *goals* for the *activities* undertaken; in turn, the goals are achieved by means of specific *operations* that depend of the prevailing *conditions* that form the context for the activities.

Leont'ev also stresses that the person's ties with the environment become mediated by the culture that the person is in, and so "society produces the activity of the individuals it forms" (Wertsch, 1981, p. 46). This seems like quite a Soviet-era perspective, but the more general point that cognitive operations reflect past learning as much as they reflect the current stimulus environment is really undeniable. Certainly, it was the view taken and developed by such perceptual theorists as Adelbert Ames (1951), W. H. Ittelson (1962), and F. P. Kilpatrick (1961) under the rubric of "transactional functionalism." One could also include the earlier writing of Donald Hebb (1949) in this mediational perspective, with his suggestions of cell assemblies and phase sequences; also the somewhat later work of Richard Gregory (1974), who again gave past learning a prominent role in veridical and illusory perception.

P. I. Zinchenko and A. A. Smirnov are two major Russian cognitive/educational psychologists whose approach to the study of memory was very much along the lines taken later by Craik and Lockhart (1972) and by Craik and Tulving (1975), although we had not read their work at the time our articles were published. Zinchenko's studies of memory and the goal-directed nature of activity are summarized in an excerpt from his book *Involuntary Memory*, published in 1962 and reprinted in translation by Wertsch (1981). By "involuntary memory" Zinchenko means memory for material or events that were not learned intentionally but processed incidentally for a different purpose. His ideas are set out within the framework of activity theory, and one of his main points is that the subsequent level of involuntary memory depends on the content, goals, motives, and means found in the initial activity. Specifically, he postulated that if different groups of participants carried out different actions with the same set of materials, subsequent memory for the materials would depend on whether the information involved in the initial task was at the level of an action or of an operation. Thus, "material that is the immediate goal of an action is remembered concretely, accurately, more effectively, and durably. When related to the means of an action (to operations), the same material is remembered in a general way, schematically, less effectively, and less durably" (Zinchenko in Wertsch, 1981).

Zinchenko carried out empirical studies on children and young adults to illustrate these principles. He showed, for example, that asking participants to devise arithmetic problems led to better subsequent memory for the numbers than simply providing problems for students to solve. In a further study, originally reported in 1956, but also reviewed in the translated excerpt in Wertsch (1981), Zinchenko uses a method even closer to those we employed in the Craik and Tulving experiments. In Zinchenko's study he presented 10 sets of four words in which the first word in each set was related "logically" to another in the set, associated in a "concrete" way to a second word, and unrelated to the fourth word. An example is house–window–building–fish, in which house is related logically to building, in a concrete way to window, and is unrelated to fish. There were three between-subject conditions in which participants (university students) were first presented with the words auditorily and then wrote them down. They were then asked either (according to the condition) to underline the word *unrelated* to the first word in the series, the *logically connected* word, or the word related *in a concrete fashion*. After one minute of distraction the participants were then unexpectedly asked to recall all 40 words they had just processed. The results showed that words were best recalled when they formed the goal of the action—for example, a logical relation under logical instructions and so forth. However, this connection between relation and instruction was modulated by the finding that logically related words were generally better recalled than words having a concrete relation to the first word, and both logical and concrete words were better recalled than unrelated words, regardless of the instructional condition. The means were 5.8, 4.8, and 2.3 out of 10 for logical, concrete, and unrelated words, respectively Thus, Zinchenko concludes that "material is remembered most effectively when it is connected with the goal of an action" (in Wertsch, 1981, p. 339), but these results also led him to concede that "the level of recall is determined not only by the role material plays in an activity but also by its objective content—it is also determined by the nature of its relation to the person's past experience" (in Wertsch, 1981, p. 338). That is, the stronger association between the first words and their logically connected words enables the latter to be well recalled even when they are not the goal of the action; associative meaning and past experience clearly play a role in addition to goals and operations.

A. A. Smirnov was another Russian psychologist who contributed a great deal to the understanding of memory viewed in the context of activity theory. His experiments, published originally in 1948 but re-published in translation in 1973, have the same flavor as Zinchenko's studies, although perhaps even closer to the LOP work published some decades later. In one large study described by Smirnov as "three experiments," participants processed lists of words under various conditions and then recalled them. Each experiment was conducted under both voluntary (intentional) and involuntary (incidental) conditions. For convenience I will describe the work as one study with three different conditions, with each condition comprising both incidental and intentional parts. The three conditions were performed by different groups of participants, but in each condition the same participants performed first the incidental condition and then the intentional condition. Smirnov's principal aim was to contrast the levels of memorization obtained under voluntary and involuntary conditions. The experiments involved children in grades 2 and 4, and also college students.

In the first condition, participants were read 10–15 words (depending on age) to copy down, ostensibly as a dictation exercise. After completing this phase participants were unexpectedly asked to recall as many words as possible. Following this, they were given a second set of similar words for intentional learning and recall. In the second condition, a list of words was read to a different group of participants who were instructed to say aloud any word that came to mind after hearing the word presented by the experimenter. Following this initial phase they were unexpectedly asked to recall as many as possible of the original words. As in the first condition, this first phase was followed by a second phase in which a list of analogous words was presented for voluntary memorizing and immediate subsequent recall. The third condition was similar to the second, but in this case participants were instructed to generate a word meaningfully related to the one named by the experimenter. Again, this initial phase was followed by an unexpected recall phase and then by a further list for voluntary memorization and recall. Thus, the structure of the whole study enabled the experimenter to compare recall following a set of different involuntary processing operations, and for these different conditions to be compared with intentional (voluntary) learning of similar material.

The results showed that the generation of "any word" (condition 2) resulted in the poorest recall following involuntary processing, copying yielded higher levels, and the generation of meaningful associations was associated with the highest ratios of involuntary-to-voluntary recall in all groups of participants. This experimental manipulation and pattern of results is clearly strongly related to studies conducted under the rubric of LOP, where the results also showed that levels of recall are related to the participant's level of cognitive involvement during the encoding phase, and especially to the involvement of meaning. Smirnov's own analysis is quite similar, noting that the various conditions "were selected in accordance with the difference in depth of penetration into the meaningful content of the material and in the corresponding degree of intellectual activity" (Smirnov, 1973, p. 89). He also comments with respect to the "copy" condition that writing words involves motor activity and that such an activity is also associated with good memorization.

The Russian work of Zinchenko and Smirnov is placed in a more modern context in a useful review by Meshcheriakov (2008). In this article he rightfully praises the insights of Zinchenko, in particular, and admonishes the Western psychologists who neglected his work: "It must, however, be stated that the effects investigated and the methodological techniques developed by Zinchenko long ago have since been newly 'discovered' and 'invented' by other researchers, who did not cite the man who first discovered them" (Meshcheriakov, 2008, p. 15). Oh dear, *nostra culpa*! In a reply, Craik and Lockhart (2008) readily concede that the ideas, findings, and conclusions of Zinchenko, Smirnov, and others are clear precursors of the LOP work, but point out that the "levels" ideas arose independently out of British work on perception, attention, and short-term memory (as described in Chapter 1). We also point out (rather lamely perhaps) that the Russian work was not generally available in English until the book by Smirnov (1973) and the translations edited by Wertsch (1981) were published.

In his article Meshcheriakov commented that there are at least two major components to Zinchenko's scheme:

> One of them is the impressive effect of the superiority of "activity-related" involuntary memorization over "incidental" memorization; for terminological precision it can be termed the "incorporation into activity effect." The other effect relates to the fact that material is most productively involuntarily memorized when it is part of the content of the goal of an action, compared with situations where material relates to the conditions under which the goal can be achieved. This second effect will be designated the "activity structure effect" (Meshcheriakov, 2008, p. 32).

Meshcheriakov goes on to clarify the first component by giving the example of "the superiority of involuntary memorization of text where there was an active effort to make sense of it over voluntary memorization with simple repetition" (Meshcheriakov, 2008, p. 32). He therefore includes both LOP effects and also the generation effect (Slamecka and Graf, 1978) under this rubric of meaningful activity. It might be added that experiments showing positive memory effects following the performance of "subject-performed tasks" also fit under the notion of active effort. In those experiments (e.g., Zimmer et al., 2001) participants either read a list of commands (e.g., "point to the ceiling," "lift up the watch") or actually carry out the motor actions involved in the commands. Subsequent memory performance is consistently better in the second case (see Chapter 4).

There is no doubt that the ideas of Zinchenko and Smirnov are important precursors of the notion of LOP. The central importance of mental activity, especially of a deep and meaningful kind, is clearly stated, as is the use of incidental orienting tasks to explore the consequences of various types of involuntary memory. Zinchenko also considered the process of remembering to have a creative "constructivist" aspect to it, and emphasized that repetition should not simply restore or consolidate existing knowledge, but should transform it qualitatively (Meshcheriakov, 2008, p. 19). This last conclusion obviously bears on the later distinction between maintenance and elaborative rehearsal.

Donald Hebb's cell assemblies

Donald Hebb (1904–1985) was a Canadian psychologist whose neuropsychological theory of behavior (Hebb, 1949) has had a long-lasting effect on both cognitive psychology and cognitive neuroscience. His theoretical ideas had their origin in an attempt to understand perception and perceptual learning in neural terms. He proposed that simple patterns evoke a network of linked neurons, and that repetition of the pattern strengthened the probability of members of the network firing neighboring neurons. Eventually, the network (the cell assembly in Hebb's terminology) becomes sufficiently strengthened to fire autonomously, even in the absence of the triggering stimulus—thereby forming the basis of experienced mental imagery (Hebb, 1968).

To my slight disappointment, Hebb distinguishes *perceiving*, as the process of arriving at a perception, from the *percept*—the brain process that *is* the awareness of the object perceived (Hebb, 1968). The percept is not static, however, but an active, sequentially organized temporal pattern. The processes of organization, in turn, owe much to motor processes; just as the person's visual system scans the external object, the neural correlates of these motor movements fire again when the relevant assemblies are activated in the course of imagery. Hebb also suggests that cell assemblies exist at various levels of specificity and abstraction; for example, a triangle viewed from one angle is at one level, but after viewing many triangles from different angles a superordinate assembly is formed to represent the object from any angle. This hierarchical scheme of networks thus runs from "first-order cell assemblies" that are sensory in nature through progressively higher and more general representations, culminating in a "schema" of the object—abstract conceptual activity that has no representational features (Hebb, 1968). Hebb suggests that vivid eidetic imagery (found mostly in children) is underpinned by activity in the first-order sensory assemblies, and that there is a continuum of declining vividness through hallucinations and mental imagery to the "imageless thought" involving assemblies at the highest level.

So I would classify Hebb as an activity theorist given his emphasis on cell assemblies as dynamic patterns governed by motor processes to form "phase sequences" that represent coherent progressions of perceptual–motor events. When he deals more explicitly with memory in his 1949 book, he first considers whether stable memories can be represented by continuously active networks, but he quickly rejects this notion in favor of the concept of structural change among members of a neural network. He allows that perceptual activity can be maintained for a short time by "reverberatory circuits" of cell assemblies—a clear forerunner of short-term memory—but longer-term memories are built from a more permanent strengthening of synaptic connections within a network. Such networks will then have the potential to be reactivated at a later time by associated perceptions or ideas. Hebb was a tremendously perceptive and imaginative thinker who substantially laid the groundwork for an integration of the experiential, behavioral, and neural worlds.

Jenkins and collaborators

By the 1960s, research on human memory was turning away from the "verbal learning" tradition in which learning was held to reflect the establishment and weakening of associations, and towards more "cognitive" notions in line with the ideas and findings embodied in Ulric Neisser's classic *Cognitive Psychology* book of 1967. Prominent among these new-style memory theorists were George Mandler from San Diego, Endel Tulving from Toronto, and James Jenkins from Minnesota. Tulving and Mandler broke from the verbal learning tradition by suggesting that memory for verbal material was more a matter of organization of the materials into networks and hierarchies than associative chains between items and their representations (e.g., Mandler, 1962; Tulving, 1962, 1964). Jenkins was another forward thinker whose work had always stressed the importance of meaningfulness for memory. For example, Jenkins and Russell (1952) found that if highly associated words (such as thread, needle, and mend) were placed randomly in a list to be recalled, the related words tended to be recalled together. This observation fits well with Tulving's (1962) notion of subjective organization, the idea that when participants are presented with a list of words (or other items) to remember they tend to reorganize the items into a structure that makes sense to them in light of their current knowledge and past experience. Tulving then demonstrated that greater degrees of organization were associated with higher levels of recall. So these researchers, and a number of others at that time, were beginning to talk in terms of mental operations and cognitive processes as opposed to associations, and this new set of attitudes paved the way for future work.

In particular, I focus here on a series of studies by Jenkins and his students published between 1969 and 1973. In the first of these publications (Hyde and Jenkins, 1969), the authors acknowledge that in the free recall paradigm (in which participants are presented with a list of words and then attempt to recall them in any order) greater degrees of organization are associated with higher levels of recall. Further, that organization is enhanced by meaningful relations among the list items. What was unknown, however, was the stage at which this benefit occurred; at encoding, at retrieval, or by means of an independently stored retrieval plan. They decided to examine this question by using the technique of holding the material constant but changing the processing demands of the "orienting task" that participants performed on the words as they were presented. Hyde and Jenkins attribute this method to earlier suggestions by Cofer (1965) and Tulving (1968), although, as we have seen, Soviet psychologists were already conducting experiments with such "incidental" orienting tasks. Hyde and Jenkins presented participants with lists containing 12 pairs of meaningfully associated words, distributed randomly throughout the list. Different groups of participants were instructed either simply to learn the list for a later recall test (intentional learning), to rate each word for pleasantness, to check the letter E in any word containing it, or to estimate the number of letters in each word as it was presented. Participants in the last three groups were not aware that their memory would be tested, but, in fact, all groups were given a free recall test after presentation. In essence, the results showed that the incidental "pleasantness" group recalled as many words as the intentional learning group, and that both groups showed good organization in that the related pairs tended to cluster together in participants' responses. However, the E-check and letter-estimation groups showed less clustering and substantially poorer recall. The authors concluded that the assignment of a pleasantness rating necessarily involved meaning and that meaning promoted co-activation of the paired words, thereby enhancing organization, clustering at output, and a high level of recall. They end by endorsing Tulving's proposal that it is the activation of meaning during the encoding process that is crucial for the establishment of good organization and therefore good recall.

The same general conclusion emerged from later articles in the series. Using a similar free-recall paradigm, Johnston and Jenkins (1971) compared intentional learning with conditions in which participants either generated a rhyme or an appropriate adjective to each presented word. In all cases, presentation was followed by a free-recall test. The adjective group showed almost as much clustering and almost as high recall levels as the intentional learning group, but the rhyme group scored substantially less well on both measures. The authors' argument was that rhyme generation reduced semantic processing but that generating an appropriate adjective focused attention on the word's meaning. A further article by Hyde (1973) investigated the possibility that enhanced organization and recall was fostered by tasks that involved greater mental effort. His experiment explored this idea by having participants carry out one or two orienting tasks in the same limited time, arguing that two tasks were more effortful. The results again showed that if a task involved semantic processing the subsequent degrees of clustering and levels of recalls were good, but that task difficulty or effort made no difference to performance.

Finally, two articles that appeared in 1973 (Hyde and Jenkins, 1973; Walsh and Jenkins, 1973) elegantly extended these results and essentially reported very similar experiments to those published two years later by Craik and Tulving (1975). In our defense, however, I will say that Jenkins' theoretical framework was somewhat different. The study by Hyde and Jenkins (1973) was carried out to provide further evidence for the proposal that differences in recall performance were attributable to initial *processing* differences, as opposed to differences in the type of response or in the difficulty of the orienting task performed during encoding. The authors conducted a large-scale study (almost 600 participants!) in which different groups recalled words from a list that either contained 12 associated pairs or 24 unrelated words. Additionally, the groups either knew about the subsequent memory test (intentional) or did not (incidental). Control groups simply studied the words for a later test or carried out one of the following orienting tasks: pleasantness rating; frequency estimation; check words for letters E and G; record each word's part of speech (e.g., adjective, noun, verb); or decide whether the word fitted a simple sentence frame. The results showed that intentional learning was superior to incidental learning, recall from the associated list was better than recall from the unrelated list, and that recall varied widely as a function of the orienting task. For this last variable, pleasantness rating was slightly better than intentional control, and these tasks were followed by frequency judgments, parts of speech, E–G checking, and sentence frame. The finding that "sentence frame" yielded the lowest levels of recall is at first surprising in light of the results of Craik and Tulving (1975) but understandable when one considers that the latter's sentences were rich and meaningful, whereas those in the present study took the form "It is _" or "It is the _" —largely devoid of semantic content. Finally, type of list interacted with type of orienting task; semantic tasks increased recall over non-semantic tasks by 83% for related lists but only by 42% for unrelated lists. The general conclusions were that meaning was crucial for good recall and that type of processing during learning is the major variable affecting recall, not type of response or the ease or difficulty of the learning task. Clearly, this is getting pretty close to the conclusions of the LOP group!

The study by Walsh and Jenkins (1973) essentially follows on from the Hyde and Jenkins study; again, the main point was to obtain evidence in favor of either difficulty, effort, or process explanations of good memory performance. They report three experiments, each of which had an intentional learning control group and further groups carrying out incidental encoding tasks, either singly or in pairs; the conditions involving two tasks were designated relatively difficult. Experiment 1 involved ten groups; intentional control, pleasantness rating, E–G checking, syllable estimation, and six further groups combining pairs of the three orienting tasks in each of two specified orders (e.g., pleasantness followed by E–G checking and E–G checking followed by pleasantness rating). The word list for these experiments was made up of 24 low-frequency nouns. The results are shown in Figure 2.1. In general, any conditions containing either intentional learning or involving semantic processing (pleasantness rating) was associated with good recall; the one exception is pleasantness, followed by E–G checking, regarded here as an anomalous result given that the same condition yielded higher recall levels in Experiment 2.

It is clear that combining the orienting tasks did not either increase or reduce recall levels; again, the crucial component was the need for semantic processing, either by itself or in combination with another less powerful task. Jenkins, along with Tulving, was always conscious that different final criterial tasks (e.g., recall, recognition, or some perceptual judgment) may need different types of initial processing to yield optimal performance, and this is seen in Walsh and Jenkins' final rousing statement:

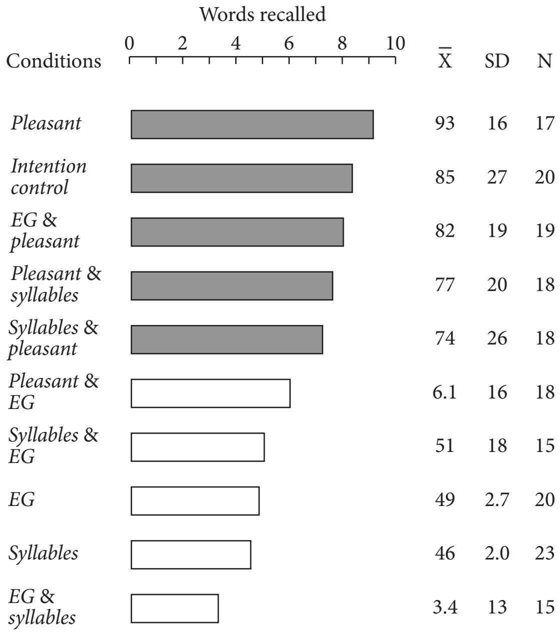

Fig. 2.1 Average number of words recalled in each condition of Experiment 1 (Walsh and Jenkins, 1973). Each condition was associated with either one orienting task (e.g., rating for pleasantness) or two tasks performed successively (e.g., syllable estimation followed by E–G checking). Shading is identical in conditions that do not differ statistically.

Reproduced from Walsh, D. A., & Jenkins, J. J. (1973). Effects of orienting tasks on free recall in incidental learning: "Difficulty," "effort," and "process" explanations. *Journal of Verbal Learning & Verbal Behavior*, 12(5), 481–488. https://doi.org/10.1016/S0022-5371(73)80028-3 with permission from Elsevier.

> The results of the experiments lead us again to the study of the nature of the orienting task and to the relation of that task to the criterion task. It is surely clear now that when the materials are English words and when the criterion task is a recall task, the aspect of the orienting task that is most crucial is whether it is semantic or non-semantic. How generally this is true for other materials and other criteria remains to be explored (Walsh and Jenkins, 1973, p. 488).

Crowder and proceduralism

Robert Crowder (who died too young in 2000) was an experimental psychologist in the grand functionalist tradition of American psychology. He was a student of Arthur Melton's at Michigan, and went on to become a faculty member at Yale, where he spent the rest of his career. His early work was principally on auditory memory, but he later became disenchanted with current models of stores and buffers, and eventually "converted" (his word!) to proceduralism as *the* guiding principle of memory theory (Crowder, 1993). I knew him mainly through our joint residence at the Center for Advanced Studies in the Behavioral Sciences at Stanford in 1982–1983. Several Fellows at the Center that year were memory researchers, so we formed a small group to discuss aspects of memory theory. An unusual occasional participant in the group's musings was Salvador Luria, the microbiologist who was awarded the Nobel Prize for his work on the genetic structure of viruses. Luria kept us grounded with his insightful questions, but I think he remained somewhat puzzled by the concepts and methods of cognitive psychology, and showed more enthusiasm for the poetry of Wallace Stevens! But the group was very influential in helping me frame my evolving views on memory as activity, and these discussions were quite possibly also influential for Bob Crowder.

In an excellent book chapter, Crowder (1993) lays out what one reviewer termed a virtual "proceduralist manifesto." He makes the point that memory storage uses the same neural units as those that processed the information initially, as opposed to using different dedicated memory stores. Also (following Kolers, 1973) that it is the encoding operations themselves that are stored, not some abstracted gist of the original event. He argues that the two major tenets of the proceduralist position are, first, that remembering is an active process, and, second, that the processing units are changed by the activity and retain these changes. Crowder then outlines four basic principles of memory from a proceduralist standpoint, as he sees them. The first is *hyperspecificity*, the idea (backed by many empirical examples) that for remembering to be successful, the retrieval operations must repeat the encoding operations exactly; the notion of an encoding–retrieval match is also embodied in Tulving's encoding specificity principle (Tulving and Thomson, 1973). Crowder's second principle is *transfer-appropriate processing* (TAP) (Morris et al., 1977), the notion that retrieval processing must match encoding processing.

As Crowder comments, this principle is thus a more general statement of the hyperspecificity principle. The third principle, *process-appropriate interference*, is basically a complement to TAP; effective interference must be in the same form as the initial memory. There are some interesting exceptions to this principle, however; Crowder cites Elizabeth Loftus's work on how verbal statements can apparently alter a person's visual memory of automobile accidents (e.g., Loftus, 1983). The fourth principle is *exemplar storage*, the notion that the whole initial experience is stored, not simply some abstracted gist. This leads to interesting questions of how abstraction works; do we obtain abstract information by computing it online from stored individual episodes, or do the common episodes fuse in some sense to represent context-free gist? I personally lean to the second alternative, as suggested later in the book. Crowder's final point is that a proceduralist account is a better candidate for mapping cognitive concepts onto neural processes—a topic addressed in Chapter 9. All in all, this chapter reflects Bob Crowder's deep knowledge of the history of research in memory and learning, and also his sensible and balanced approach to theory.

Summing up

This brief and selective glimpse of philosophical and psychological ideas preceding present-day theories of cognitive processing makes it clear that notions of "the mind as activity" have been influential for a long time. In a way it is difficult to think seriously of any *other* view of conscious cognitive functioning. Both perceiving and thinking are self-evidently activities of the mind and brain and, given their close affinity to attention and memory, it makes sense to think of the latter constructs also as the activities of "attending" and "remembering"—as verbs rather than as nouns. However, it must be conceded that *something* in the brain is changed as a result of experience, and that the change is fundamental to subsequent remembering. In line with a processing view, my proposal is that the analytic machinery of perception and comprehension is subtly altered by each fresh experience and that the activity of the altered analyzers, in interaction with further incoming information, underlies the experience of remembering. Everyday notions of memory lead rather naturally to thoughts of a dark storehouse of past experiences from which we select specific items to examine in the bright light of conscious awareness. The stores metaphor leads, in turn, to questions of capacity, of *the* way in which memories are represented in different stores, and of how items are lost—through decay or displacement, for example.

The Craik and Lockhart article rejected such structural notions and replaced them with the idea of remembering as a process or related set of processes. This different perspective prompted different questions, concerned, for example, with different processing operations, the qualitative codes represented by these operations, and their efficacy in supporting later memory experiences and behaviors; also with the distinction between primary and secondary memory, and between episodic and semantic memory. As detailed later, I consider the primary/secondary memory distinction to be a categorical one—information is either in conscious awareness (primary memory) or is not (secondary memory)—but I consider the episodic/semantic distinction to describe levels of a continuous hierarchy of representations running from highly specific to generalized and abstract. These various points are discussed more fully in the next chapter.

3

Remembering

A Personal View

In this chapter I will set out some ideas about the nature of memory and remembering based on my own research findings and interpretation of other current findings in the field. Most of the notions and perspectives have been suggested by various other people at various other times, and I make no great claims to originality for any of the components. It's just that the package as a whole sums up my current views, and this, in turn, will serve as a framework within which to assess the empirical finding described in later chapters.

To my mind the search for a unified coherent theory of human memory has been impeded by an overabundance of different types of memory. The major divisions suggested by theorists over the past 50–70 years include short-term and long-term memory, episodic and semantic memory, declarative and procedural memory, implicit and explicit memory, sensory memory and working memory (WM). Additional constructs include primary and secondary memory, prospective and retrospective memory, autobiographical memory, the articulatory loop, visual cache, episodic buffer, phonological buffer, and probably others. No doubt these suggested structures, mechanisms, and processes have been useful in clarifying and systematizing results from younger and older participants, as well as from patients with memory disorders, but it is less clear how they all fit together to provide some unified picture of how memory is structured and how it functions.

The chapter presents my current views on such issues, illustrated by some relevant studies, and by quotations from my past musings and from the writings of others. It may be helpful here to present a short outline of the main points covered; this may act as an organizing framework to make more sense of the specific points presented later. Rather than describe memory systems in psychological terms such as "short-term memory" (STM) and "long-term memory" (LTM), I make the case for understanding the phenomena of memory in terms of the qualitatively different "codes" (e.g., phonological, visual, semantic) that the brain uses to represent information and events. I do, however, maintain the Jamesian distinction between "primary memory" (PM) and "secondary memory" (SM), defining PM as active conscious processing of incoming or retrieved information, and as "attention paid" to a variety of encoded items and events. SM is described as a system of *representations* rather than as a memory system as such, but I prefer to think of the representations as active systems of analysis whose analytic operations "stand

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for" incoming or remembered events. It is also important to point out that many of these analytic operations represent plans for action—for outputs as opposed to inputs. I also believe that the distinction between episodic and semantic memory is a useful and, indeed, necessary one, but I make the case for viewing these constructs as lying on a continuum from episodic specificity to semantic abstraction, rather than as independent systems. I stress the role of the external context in encoding and retrieval, and the role of executive processes in enabling "self-initiated activities" when such environmental support is absent. Finally, I cite the ideas of Paul Kolers and Larry Jacoby, and endorse their notions of remembering as a set of active analytic operations and of the similarity between the operations underlying remembering and perceptual processes.

Qualitative codes and representational systems

One feature of the many divisions of memory cited earlier is that they are all defined in terms of psychological or behavioral differences. This is entirely understandable given that the experiences, observations, and experimental data they are based on are also largely psychological and behavioral. The *brain* may take a different view, however. That is to say, the organization of brain structures and functions giving rise to the various phenomena of memory may not necessarily reflect psychological differences in any direct way. Rather than analyzing memory in terms of stores, buffers, or systems based on psychological properties, I prefer to talk directly about qualitatively different *coding* or *representational* systems. So, for example, rather than postulate a short-term store that may utilize phonological, articulatory, visual, and perhaps semantic information, I have argued in the past that we should describe phonological, articulatory, visual, and semantic codes (or representations) directly in terms of their qualitative and quantitative characteristics, and regard their mnemonic properties as interesting byproducts.

In an article by Levy and Craik (1975) for example, we explored the characteristics and coordination of phonemic and semantic codes in the short-term retention of word lists. Specifically, we asked whether these two codes would trade off against each other if both were present (e.g., Would more emphasis on phonemic encoding result in less effective semantic encoding?). Alternatively, could one code *compensate* for interference in the other code? And, finally, could codes be additive, resulting in enhanced performance when two codes were present? In one experiment (Levy and Craik, 1975, Experiment II) participants were presented with 12-word lists for immediate free recall. The words were presented visually; on half of the lists each word was also presented auditorily. Additionally, on half of the lists the 12 words were unrelated and on the other half all words in a list were drawn from the same semantic category. These four presentation conditions—visual only, visual plus auditory, unrelated, and categorized—were crossed such that there were four combinations: visual/unrelated; visual/categorized; auditory/unrelated; and auditory/categorized. Five lists were presented in each of the four combinations, and recall was written in all conditions. Participants were instructed to recall the final few words on each list first of all, and then as many words as they could from the rest of the list. After all 20 lists were presented and recalled participants were given an unexpected final recall test in which they attempted to recall again words from all previous lists. The questions of interest included the possible boosting effects on recall of providing additional phonological information (auditory stimuli) and additional semantic information (categorized lists); also, would the two codes be additive or would they trade-off against each other when both were present?

The results are shown in Figure 3.1 for both (a) immediate recall and (b) final delayed recall. Results from delayed recall show clearly that the additional semantic information boosted recall across all 12 serial positions, but that the additional phonological information had no effect. The same pattern holds for the first eight serial positions in immediate recall, but in the final four positions the additional phonological information clearly boosts recall. This pattern is shown for serial positions 8–12 in Table 3.1; in delayed recall there was a significant effect of semantic relatedness but no effect of phonology, whereas in immediate recall there were significant effects of both phonology and semantic relatedness but no interaction. A further experiment showed exactly the same pattern of differences between immediate and delayed recall when all words were unrelated but one group of participants was instructed to process the words semantically by relating words in a list together in sentences, stories, or mental pictures, and a second group was instructed to rehearse by simply naming the words to themselves. Thus, the semantic code may be induced by the words themselves or induced strategically by constructive activities.

It is possible to take these results as good evidence for a "short-term memory system" that uses auditory information but loses effectiveness in a few minutes, and for a "long-term memory system" that uses semantic information and is longer lasting in its effectiveness. The problem that I see with this approach is that the short-term system can use articulatory information, visual information, or even tactile information (Watkins and Watkins, 1974b), and that the characteristics of the system change as a function of the particular coding modality used and type of material held (see also Craik and Lockhart, 1972). So, rather than defining a memory system in terms of its temporal characteristics—and then having to grapple with the store's apparently different characteristics depending on materials, presentation modalities, and participants' strategies—I strongly prefer to focus on the different representational codes themselves, their characteristics, and qualitative natures. Another way of saying this is to argue that we should not focus first on memory behavior as such and then attempt to understand how one

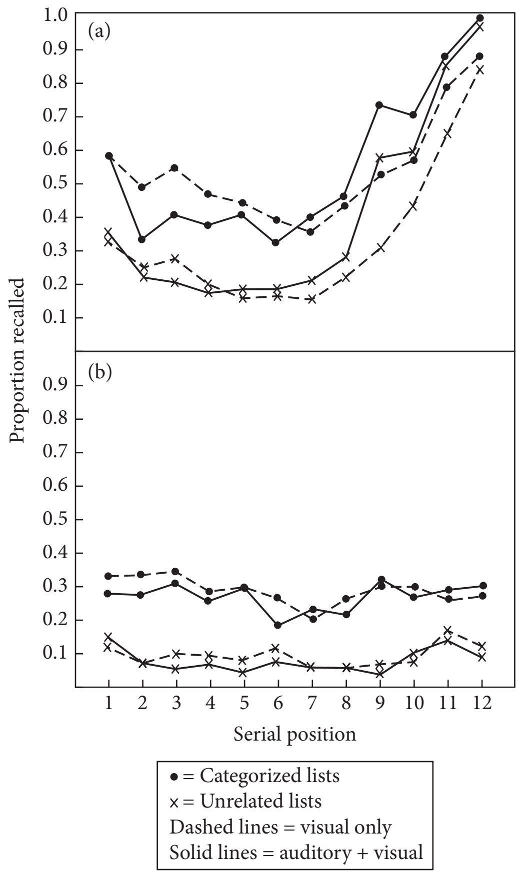

Fig. 3.1 Serial position curves as a function of encoding and retrieval conditions (Levy and Craik, 1975, Experiment II). (a) shows immediate recall; (b) shows delayed recall.

Reproduced from Levy, B. A., & Craik, F. I. M. (1975). The co-ordination of codes in short-term retention. *The Quarterly Journal of Experimental Psychology*, 27(1), 33–45. https://doi.org/10.1080/14640747508400462 with permission from SAGE Publications.

postulated entity (e.g., STM) should behave differently as a function of the specific codes utilized, but rather we should focus directly on the representational systems themselves, their characteristics, how they are generated, how they interact, and how they affect memory performance. So, in a sense, "memory" is the objective outcome or product of processing, and provides the basis for implicit and procedural memory, as well as the explicit memory for facts and events, whereas "remembering" is the subjective experience of the processing operations themselves, carried out by specific representational systems (although see also Chapter 1 for further reflections on the use of the term "remembering").

Table 3.1. Mean proportions of words recalled from serial positions 8–12 in immediate and delayed recall as a function of presentation modality (Levy and Craik, 1975, Experiment II)

Retention Interval:	**Immediate**		**Delayed**	
Semantic Relatedness:	**Categorized**	**Unrelated**	**Categorized**	**Unrelated**
Modality: Aud + Visual	0.74	0.65	0.29	0.10
Visual only	0.63	0.48	0.29	0.12

Reproduced from Levy, B. A., & Craik, F. I. M. (1975). The co-ordination of codes in short-term retention. *The Quarterly Journal of Experimental Psychology*, 27(1), 33–45. https://doi.org/10.1080/14640747508400462 with permission from SAGE Publications.

Primary memory as active conscious processing

I now wish to expand this notion to suggest that all types of memory are best understood in terms of their component codes (or representational systems), how they are constructed, how they are changed in the course of learning, and how they are affected by different encoding and retrieval conditions. Despite my emphasis on codes and representations, as opposed to stores and buffers, I do want to make one major distinction—between primary and secondary memory, in the sense used by James (1890) and Waugh and Norman (1965). PM refers to the small amount of material that a person can hold in mind, in conscious awareness, and SM refers to "memory proper"—the personal episodes and pieces of learned knowledge that a person can retrieve and bring into consciousness. But I want to add some amendments to the PM/SM distinction. The first is to suggest that PM is essentially equivalent to "attention paid" to some aspect of the information held. To rephrase this idea in terms more congenial to the theme of this book, I suggest that PM reflects *active conscious processing* of a variety of different types of information. This notion has also been proposed by various researchers in their descriptions of WM. For example, Baddeley (1993) has written that attention clearly plays a major role in the central executive component of the Baddeley and Hitch model, although he prefers the term "working *memory*," given that temporary storage is the essential feature of the system as a whole. Other current cognitive theorists (Cowan, 2008; Engle, 2002; Fuster, 2002; Oberauer et al., 2000; Unsworth & Engle, 2007) have made attention a salient aspect of their view of WM, and the recent thinking in cognitive neuroscience is quite explicitly that the phenomena of WM should be regarded as attention paid to a variety of different representations (e.g., D'Esposito and Postle, 2015). I have suggested similar ideas myself in previous publications, for example "The view of coding which I prefer is that 'storage in PM' may be equated with 'attention paid to auditory, articulatory or (occasionally) visual cues'" (Craik, 1971, p. 235). And, again, "In our view, such descriptions as 'continued attention to certain aspects of the stimulus,' 'keeping the items in consciousness,' 'holding the items in the rehearsal buffer,' and 'retention of the items in primary memory' all refer to the same concept of maintaining information at one level of processing" (Craik and Lockhart, 1972, p. 676). But I must ruefully concede that brilliant early insights are not enough to influence science in meaningful ways! The ideas, rather, must be developed theoretically and fleshed out by programs of empirical research.

I will return to the topic of PM in the chapter on WM, but here are a few more theoretical points about PM before turning to SM. First, do I endorse the idea that PM simply reflects the temporary activation of SM structures? This notion has been suggested by a number of people over the years, including Shiffrin (1976), but also rejected by others, including Baddeley and Logie (1999). I *do* endorse the temporary activation view, and believe that there is mounting evidence that WM involves the joint activation of frontally based processes (the "attention" or "executive function" component) and specific posterior regions and processes, reflecting the specific type of material being held or worked on (e.g., Fuster, 2002; McIntosh, 1999; Postle, 2006). So, by this view, PM does not exist "in one place" either cognitively or neurologically, but reflects activation in brain regions dedicated to the processing of the material currently "held in working memory."

Second, the limited capacity characteristic of PM stems from the limited resources associated with attentional processing, although it should be noted that span measures of "STM capacity" may include a component retrieved from SM. This latter suggestion is illustrated by the sketch in Figure 3.2. The probability of retrieval is taken to be 100% for information still in PM (in conscious awareness), but

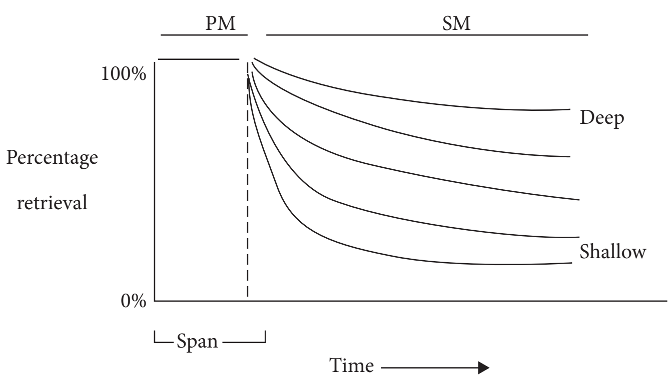

Fig. 3.2 Sketch showing hypothesized percent retrieval rates from primary memory (PM) and secondary memory (SM) as a function of time since presentation.

my suggestion is that measures such as word span and digit span are augmented by recently activated information retrieved from SM. The curves showing forgetting as a function of time since the material was dropped from PM are assumed to reflect depth of processing, so that deeply processed information is still highly available if "rescued" from SM soon after it was last in PM.

One piece of evidence backing this last claim comes from a free recall study (Craik, 1970) in which word span was also measured. Free recall performance was attributed to PM if no more than six items (presentations or responses) intervened between a word's presentation and its recall (Tulving and Colotla, 1970); further words recalled were considered to be retrieved from SM. In the study, word span performance correlated more highly with the SM component of free recall (*r*, 18 = + 0.72) than with the PM component (*r*, 18 = + 0.49). This point is discussed more fully in Chapter 6. A final point about the nature of PM is that whereas in the 1971 article I suggested that PM reflected "attention paid to auditory, articulatory or (occasionally) visual cues" and that semantic effects in short-term retention are due to retrieval from SM, I now prefer to be more inclusive about the nature of PM, suggesting that any aspects attended to and in conscious awareness—phonology, articulation, images whether auditory or visual, *and* meaning—are all "in PM." Again, this point is discussed more fully later.

Secondary memory and representational systems

The main point I want to make about long-term or secondary memory is that it is *not* a memory system! Rather, "retrieval from SM" connotes reactivation of *representations* of episodes, experiences, knowledge, and facts, built up at times running from a few moments ago to many years in the past. Further, I suggest that this large and varied system of representations may be organized in various ways, one of which is clearly along the lines proposed in classic papers on semantic memory (e.g., Collins and Loftus, 1975; Collins and Quillian, 1969; Rips et al., 1973) in which conceptual and factual knowledge representations are organized in hierarchical categories. Thus, my dog Fido is one exemplar of spaniels, which are, in turn, nested under dogs in general, and—finally—under mammals, animals, and living things. I have proposed an alternative classification, also running from highly specific to general, to suggest that episodic and semantic memory may be regarded as levels of representation in a hierarchical scheme (Craik, 2002, 2007). The idea is illustrated in Figure 3.3.

Specific episodes are represented as occupying the lowest nodes in the hierarchy, higher nodes represent commonalities between similar episodes, and still higher nodes represent abstract, context-free concepts summarizing the information nested beneath them. The episodic–semantic distinction is thus maintained, but

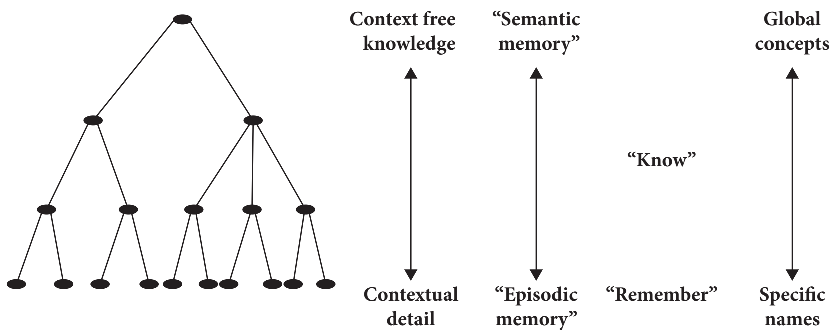

Fig. 3.3. Hierarchical model of knowledge representations.
Reproduced from Craik F. I. M. Levels of processing: past, present… and future? *Memory*. Sep–Nov;10(5–6):305–18. doi: 10.1080/09658210244000135 with permission from Taylor and Francis.

re-envisaged as a continuity of specificity, ranging from the highly specific contextual detail of a single episode to the context-free concepts of general semantic knowledge. In their influential article on the complementary learning systems associated with the hippocampus and the neocortex, McClelland, McNaughton and O'Reilly (1995) propose a very similar scheme. Figure 3.3 makes the point that the lowest levels of representation may be usefully designated "episodic memory" and the highest levels "semantic memory," but (in my opinion) this categorical division masks what is essentially a continuum of specificity. In a similar vein, the remember/know distinction (Gardiner and Richardson-Klavehn, 2000; Tulving, 1985) has been helpful in illuminating empirical problems in memory research, but again I would suggest that these terms reflect a participant's degree of access to the original context attached to an event. In a word-list learning experiment participants judge they "remember" a word if they recollect some association or passing thought they experienced when the word was presented but give a "know" judgment if they feel sure the word was in the list but cannot recollect any specific context. So, "know" judgments are clearly still "episodic"—they refer to events occurring at a particular time and place; it's just that "remember" judgments carry with them a greater degree of contextual specificity. If the participant was asked after a week whether the word *rhinoceros* was one she encountered in the experiment, she might answer "yes" with some confidence but have no idea which list it came from. A year later she knows the meaning of rhinoceros but has no recollection of studying it in the experiment. In other words, recollection of context is not all-or-none, but comes with various degrees of precision and specificity. I should perhaps stress that this proposed hierarchical organization is not the *only* possible way that SM representations can be ordered and organized. For example, the similarity between constructs (both concrete and abstract) enables similarity judgments and reasoning by analogy. Just as a set of objects can be ordered and classified in various ways—in terms of size, weight, color, or value, for example—so mental representations can be ordered and organized, depending on the person's current interests and goals.

What exactly is gained by the proposal that information in SM constitutes "representations" rather than "memories"? My argument rests largely on the different questions prompted by this pretheoretical assumption. So rather than attempt to characterize different stores, systems, or types of memory defined in psychological terms, we should be exploring how sensory representations are integrated into higher-level representations of sounds, colors, edges, and odors, then into letters, words, and objects, and, finally, into concepts and conditional plans for action. To be slightly more radical, but in line with an overall "activity" view of cognition, I argue that the representations that constitute SM are more properly systems of *analysis*. Rather than think of representations as dedicated networks of learned information waiting passively to be activated by relevant inputs, we should think of SM as an extremely large and complex *analytic* system, working initially on sensory inputs, and also working constructively at higher levels to interpret and comprehend situations in terms of previously acquired knowledge and to prepare and organize appropriate responses. By this view, novel complex inputs will be understood in terms of existing higher-level analytic systems, but presumably if such novel inputs are repeated often enough new high-level analyzers will be constructed to represent the new information. This viewpoint is essentially in line with the idea of cognition actively working on the environment rather than reactively responding to environmental stimulation—as advocated by Neisser (1967), Bartlett (1932), and others discussed in Chapter 2. To avoid awkward phraseology I will simply refer to "representations" in further discussions but with the underlying assumption that representational systems achieve their representing by means of active analytic processing.

While I am in this radical mode let me further suggest that memories of all sorts are not "records" of previous experiences or of acquired concepts but, in line with the notion that representations are aspects of analytic machinery, are modifications of that machinery. So the idea is that the analysis (perception, encoding) of each new event changes the whole cognitive analytic system in some minimal yet detectable way (see McClelland et al., 1995, for a similar view). I must also assume that the specific set of analyzers involved in encoding some current event primes this set—including contextual detail—so that the specific "episodic network" can be activated more readily when some component of the network is encountered (and again analyzed) on a subsequent occasion (see Chapters 5 and 10 for further thoughts on priming). So "memory" by this view is not an archive of records, but is rather a highly complex, exquisitely sensitive, analytic system that gives rise to the experience of remembering through reactivation (in part) of the same set of analyzers concerned with processing the original event.

Remembering as active analytic operations

These are not original ideas; they have also been proposed with various degrees of clarity and specificity by a number of investigators in the past. My own major personal influence is the work of Paul Kolers, who was latterly a faculty member at the University of Toronto, and who died in 1986 while still on the faculty. Kolers was essentially a visual perception researcher, but when dropped into the pool of Toronto memory researchers including at that time Bennet Murdock, Endel Tulving, Norman Slamecka, Fergus Craik, Robert Lockhart, Morris Moscovitch, and Colin MacLeod, he was either stimulated—or more likely goaded!—into carrying out memory experiments on his own account. His ideas are set out in a series of articles and chapters of which the following are representative: Kolers (1973, 1975, 1979) and Kolers and Roediger (1984). His view of remembering was that initial perception was carried out by pattern-analyzing operations and that remembering consisted essentially of repetition of these same operations (Kolers, 1973). In his system there are no "memory records" as such, simply analytic procedures and operations that are repeated at the time of remembering. In a 1975 article he wrote:

> In the theory proposed here, conscious selection and evaluation are not required for memory. There is no deposit of information in some memory bank or store that is matched or referred to by a later encounter. Rather, the nervous system in its encounters with stimuli acquires and uses skills in encoding them; it does so by engaging in a "dialogue" with the stimuli of such a kind that repeated encounters modify the encoding operation. Memory then is not traces that are matched to a stimulus (or vice versa) but procedures, operations, ways of encoding the stimulus that are used, and these change as a function of encounters with the stimulus (Kolers, 1975, p. 700).

I was always sympathetic to these notions and basically *wanted* to believe them, but I had problems with some aspects of Kolers' account. For example, there is no doubt that participants can be presented with words to remember in a visual mode yet recognize them when presented auditorily at test. Clearly, the "pattern-analyzing operations" are quite different, yet recognition can be excellent. We must assume that recognition can also occur by virtue of repetition of higher-order processes representing words and their meaning, and I now see that if the analytic machinery is organized in a hierarchical manner from sensory analyses to conceptual analyses, this objection is not a problem. A second problem was to see how repetition of operations accounted for the recollection of specific events. As I wrote previously in a comment on Kolers' views:

> Well-known events or situations are analyzed skillfully and easily by well-practiced analytic operations; it follows that feeling of familiarity could be correlates of the ease with which the analyzing routines are executed. However, I do not see how such accounts can handle remembering a specific episode. What corresponds to the knowledge that something similar to a present experience has occurred previously, perhaps in a somewhat different context? In pattern-analyzing terms how can a fragmentary retrieval cue in recall lead to the successful reconstitution of the original experience? (Craik, 1979, p. 453).

I now believe that some version of "pattern completion" must take place; once a portion of a recently activated analytic network is re-presented there is an inherent tendency of the system to complete the network—including those parts of the network that have encoded aspects of the initial context. By this means, re-presentation of a strong context can, indeed, reconstitute enough of the relevant network to enable remembering of events that occurred in that context. The notion of pattern completion is now widely accepted in cognitive neuroscience (e.g., Rolls, 2013), and is also inherent in current versions of constructivist views of memory (e.g., Schacter et al., 1998). It is also necessary to propose that top-down activation of an "episodic network" can also occur—for example, asking a friend to recount details of a previous meeting. The current notion of pattern completion is clearly related to the classical verbal learning concept of associative learning. That is, a particular stimulus or context will often (intentionally or involuntarily) evoke some further thought, concept, or remembered episode. Although "associationism" is "yesterday's theory" in many people's minds, it seems to me that associations in some form must play a major role in any complete theory of memory and learning. Perhaps the difference is that in older schemes the notion of "association" was a rather abstract construct signifying a link between two existing mental entities, a more modern view embraces semantic content. That is, if two constructs are "associated," they are linked by virtue of a change in meaning in either the constructs themselves or in their combination.

A final bothersome question relating to Kolers' perspective is the point that if remembering is essentially the reactivation of the same configuration of analytic operations that occurred during perception/encoding—how do we know we are "remembering" a previous occurrence as opposed to simply "perceiving" the current scene? One possible answer stems from the mismatch between the remembered context and the current context; when we look out the window on a rainy winter's day we know that we are not actually on the hot beach of a remembered summer holiday! Tulving (1983) has also suggested the notion of a "retrieval mode" in which the processing system is set to retrieve some sought-for event by holding relevant contextual information in the background of focal attention, and treating both bottom-up incoming information and top-down constructed information as cues to "re-present" the wanted memory. Setting the analytic system into retrieval mode has since been identified as a function of specific regions of the prefrontal context (Lepage et al., 2000). The ordinarily clear distinction between perceiving and remembering may actually be blurred in certain cases. In dreaming, for example, I assume that we mentally construct experiences by activating portions of our analytic perceptual/conceptual machinery and actually believe that we are participating in the events. Some pathological cases of hallucination may also fall into this category.

One other person who has been a major influence on my thinking in this respect is my friend and colleague Larry Jacoby. He has been a consistent advocate of an active processing approach to remembering, and has contributed a number of highly influential articles in favor of this perspective. One of his important findings was that whereas a levels-of-processing (LOP) manipulation at encoding had a large effect on later recognition memory, the manipulation had no effect on the ability to identify words presented in a very brief visual flash, although prior presentation did affect this latter perceptual identification test (Jacoby, 1983; Jacoby and Dallas, 1981). Rather than attribute this difference to different memory systems, however, Jacoby proposed that the two tests simply relied on different types of information—perceptual in the case of perceptual identification and semantic in the case of recognition memory. Jacoby also proposed that the ease or fluency of perceptual processing can serve as a basis for the feeling of familiarity in recognition memory and went on to argue that recognition memory was based on two types of information, relative perceptual fluency, and elaboration. In later articles Jacoby made it clear that familiarity in recognition memory was not based on *perceptual* fluency alone, but also on the global similarity between a test item and memory for earlier presented items. Additionally, he endorsed Kolers' view that it is the operations used to process an item in the context of a particular task that are stored in memory (Jacoby, 1991). One further contribution is Jacoby's proposal that the subjective feeling of remembering involves an attribution of current processing to memory rather than to perception; in other cases, memory of a recent event may be experienced as a difference in perception. As an example Jacoby, Allan, Collins, and Larwill (1988) found that when participants listened to sentences embedded in noise, judgments of noise levels were less for sentences that had been presented previously than for new sentences. In turn, such attributions are heavily influenced by the person's current cognitive goals and by the prevailing context (Jacoby et al., 1989). In all these ideas Jacoby blurs the distinction between memory and perception—the two cognitive modes are heavily interdependent.

Another aspect of the perspective on remembering that I proposed some paragraphs previously is the idea that the whole analytic machinery is subtly altered by each new encountered event. A version of this notion was suggested by John Bransford and colleagues from a Gibsonian point of view of perception and action. In their account, learning consists of increases in the cognitive system's ability to differentiate aspects of the stimulus array, a further refinement, or development of what is already known. Growing knowledge and expertise are the end results of such experiences, especially if the learning experiences are somewhat varied, allowing greater generalizability of the knowledge and greater amounts of transfer from one situation to another. Again, there is no system of records associated with remembered events, just the "transfer-appropriate processing" or similarity of analysis from one encounter to another (Bransford et al., 1979; Bransford et al., 1977; Morris et al., 1977). So, as I understand these theorists, remembering is again a question of repetition of processing operations without the need for memory traces as such.

Roles of the environment

When attempting to understand the various changes in memory functioning and performance that take place in the course of healthy aging (e.g., Craik, 1983, 1986) I have found it useful to acknowledge the role of the external environment in remembering. By this argument the environment is not simply a supplier of cues that trigger a memory system that resides entirely within the head. Rather, mental processes and environmental constraints should be thought of as complementary aspects of one cognitive system. To quote myself:

> Memory should not be thought of as some attribute or characteristic of the organism alone; rather, the activity of remembering, like the parallel activity of perceiving, must be understood as the interaction of such external factors as cues and task demands with internal mental operations. Just as perceiving necessarily involves an interaction between stimulus and organism, so remembering also reflects an interaction between environmental and organismic factors (Craik, 1986, p. 410).

This emphasis on interactions (or transactions) between the mental and physical worlds is also found in the arguments of proponents of "distributed cognition" and "extended mind." For example, "the human organism is linked with an external entity in a two-way interaction, creating a *coupled system* that can be seen as a cognitive system in its own right" (Clark and Chalmers, 1998, p. 8). In the same vein, Michaelian and Sutton (2013) argue that cognitive processes "spread beyond the boundaries of skin and skull" (p. 3), and Hutchins (2014) argues that cognition may be viewed as *emerging* from the interactions among mental and environmental elements. Hutchins then suggests that the interesting questions are not "whether" cognition is distributed or not. "Rather, the interesting questions concern the elements of the cognitive system, the relations among the elements, and how cognitive processes arise from interaction among those element" (Hutchins, 2014, p. 36). Hutchins goes on to comment that the distributed cognition perspective makes no empirical claims—it is a pretheoretical point of view—but I have certainly found the perspective to provide a useful framework, initially as a way to understand age-related memory impairments.

More will be said in Chapters 7 and 8 about differences in remembering as a function of aging, but here is one example of a study showing that typical age-related decrements in memory performance can be alleviated, and even abolished, by giving the external environment a greater role in overall processing. The general argument is that both encoding and retrieval processes are inefficient in older adults but can be "repaired" by providing more *environmental support*. In experiments on memory for words, this can be accomplished, first, by substituting pictures of objects for their names as stimuli during encoding, and, second, by giving a recognition test rather than a recall test at the time of retrieval. The suggestion is that the richer pictorial stimuli drive deeper encoding processes than words (which may require effortful processing to obtain the same end result) and also that re-presenting the encoded stimulus in a recognition test again drives retrieval processes in more relevant directions. These notions were illustrated in a simple experiment on younger and older adults reported by Craik and Byrd (1982). Two lists of 32 objects were presented to younger and older adults to learn for a later test. In each list half of the objects were words and the other half were presented as line drawings. After each list participants recalled as many items as they could by writing down words; and after both lists were presented and recalled participants were given a recognition for all 64 objects in which the test stimuli were all words.

The results are shown in Table 3.2. In the "unsupported" case for recall of words, the younger adults recalled almost twice as many items as did the older adults. For recall of drawings, both age groups increased their recall scores by 0.19. For recognition of words, both age groups improved their performance relative to recall, but now the age difference in performance decreased to 0.10. Finally, for recognition of objects initially presented as drawings (but now re-presented as words) the age difference was eliminated. Our interpretation of this pattern of results was

Table 3.2. Age differences in recall and recognition of words and pictures (Craik and Byrd, 1982)

Participants	**Recall**		**Recognition**	
	Words	**Pictures**	**Words**	**Pictures**
Young	0.33	0.52	0.73	0.84
Old	0.17	0.36	0.63	0.83

Reproduced from Craik F. I. M., Byrd M. (1982) Aging and Cognitive Deficits. In: Craik F. I. M., Trehub S. (eds) Aging and Cognitive Processes. Advances in the Study of Communication and Affect, vol 8. Springer, Boston, MA. https://doi.org/10.1007/978-1-4684-4178-9_11 with permission from Springer Nature.

that older adults profit differentially from the provision of environmental support at encoding and retrieval. In a sense, older adults still possess the *potential* to encode and retrieve successfully, but progressively their executive function processes need to be boosted by external support. In the absence of such supports, encoding and retrieval processes must be guided and driven by "*self-initiated activities*," and we argue that it is those activities that decline in efficiency with advancing age. Further examples of this age-related need for environmental support are given in Chapter 7, along with evidence for relevant age-related brain changes. The general conclusion in the context of the present chapter is that a complete understanding of remembering requires an acknowledgment of the role of environmental factors during both encoding and retrieval.

Roles of executive functions

Remembering may be easier when it is initiated, controlled, and supported by environmental factors, but obviously the more usual case is when the appropriate processes are initiated and controlled from within the organism itself. My assumption is that the source of such self-initiated activities lies within the frontal lobes, and that the activities themselves constitute one aspect of the brain's executive functions. During the encoding phase, executive functions may work to elaborate perception of the event by associations and images, enrich the encoding by creating sentences or stories, and enhance the potential for later retrieval by both embedding it in an organized framework and rendering it as distinctive as possible. At the time of retrieval, executive functions may boost performance by utilizing such deliberate strategies as generating cues and retrieving relevant contextual details. Older adults often experience problems with retrieval both of specific episodes and of specific details of general knowledge, such as names. Although one problem supposedly deals with episodic memory and the other with semantic memory, the common element may be an impairment of the older executive function's ability to access highly specific information of any type. Older adults can typically retrieve general information about events and general factual knowledge but often seem to lack the "resolving power" to access specifics (see also Fuster, 2002). Finally, as discussed earlier, executive functions play a key role in WM, both as attention being paid to aspects of incoming events or reactivated representations, and as the source of controlled manipulations of the material held.

More on primary and secondary memory

With regard to the idea that PM or WM is not a memory store in any sense but reflects the processes of attention engaging with a wide variety of qualitatively different representations, I would say that this is now largely accepted as the current view of what WM "is" (Cowan, 2008; Engle, 2002; Fuster, 2002; Oberauer et al., 2000; Unsworth and Engle, 2007). In a 1999 chapter Alan Baddeley remarked that he preferred to call the construct "working memory" rather than "working attention" given that temporary memory was its major function. My point here is that while memory is certainly one of WM's main functions, information may be "held in WM" by means of active processing interactions between attentional processes and processes representing the material being held (e.g., Fuster, 2002; McIntosh,1999; Postle, 2006). Some statements of this point of view include "Attention, which is physiologically a process of selective allocation of neural resources, is inseparable from working memory and from set" (Fuster, 2002, p. 102) and "it appears increasingly plausible that a working memory network is an activated long-term memory network with perceptual as well as executive components" (Fuster, 2002, p. 105). Similarly, McIntosh (1999) proposed that working memory reflects the interactions of prefrontal cortex with other brain regions. And Postle (2006, p. 23) suggested that "working memory functions arise through the coordinated recruitment, via attention, of brain systems that have evolved to accomplish sensory-representation, and action-related functions." As a final illustration of how findings from cognitive neuroscience are sharpening and clarifying cognitive concepts, utilization of the phonological store in the Baddeley and Hitch (1974) model of WM has been shown to activate the same neural circuits as those that process phonological and linguistic information (Buchsbaum and D'Esposito, 2008; Hasson et al., 2015). One implication of this view is that patients who exhibit a deficit of "auditory STM" (e.g., the patient KF described by Warrington and Shallice, 1969) may essentially be showing a deficit of phonological processing rather than a deficit in STM per se.

The notion that the neural correlates of SM or LTM are neuronal networks representing both specific autobiographical memories and general knowledge is now generally accepted in current cognitive neuroscience circles. The further idea that specific episodic memories may converge and integrate to form context-free semantic memory representations was suggested in Figure 3.3 (see also in Craik 2002, 2007). Fuster has suggested similarly that "Both the structure and contents of long-term memory consist of hierarchically-organized neural networks. The representations of action increase in generality and abstraction from the bottom up, from the elementary motor networks of primary motor cortex to the most general and abstract representations of action in lateral prefrontal cortex" (Fuster, 2002, p. 98). Here Fuster is referring to the representation and organization of actions, which parallel (or complement) my emphasis on the gradual transformation of perceptual inputs to abstract conceptual knowledge.

The Craik and Lockhart (1972) article is widely portrayed as attempting to demolish the distinction between STM and LTM. This is simply untrue (Craik, 2002). We argued against the concept of a separate short-term *store* but, in fact, maintained the general "STM/LTM" distinction, although in our framework the *structure* of STM was replaced by the *active process*es of PM. In the same vein, I am *not* arguing to abolish the descriptive distinction between episodic and semantic memory but, rather than postulate two categorically different and independent systems, I am suggesting rather that the two constructs should be viewed as a continuum running from episodic specificity to semantic generality. The idea that secondary or long-term memory should be thought of as a set of hierarchically organized active processes was one major message of the LOP framework proposed by Craik and Lockhart (1972). So when I now suggest that LTM should be regarded as a system of potentially active *representations* rather than as a memory system per se, this is perhaps nothing too new. Clearly, some of these representations encode context-free general knowledge, whereas others refer to autobiographical events located in remembered time and place. But, in my opinion, "autobiographical memory," usefully analyzed and illustrated by such colleagues as Martin Conway and Brian Levine (e.g., Conway, 2005; Conway and Pleydell-Pearce, 2000; Levine et al., 2002; Svoboda et al., 2006), is not a separate system but rather knowledge incorporating specific contextual attributes, as well as attributes pertaining to the "self." The further idea that LTM representations are essentially components of perceptual and conceptual analysis complemented by active neuronal networks that are preparations for action is perhaps somewhat novel. I acknowledge that the notion of networks encoding representations that are then "activated" by cues or thoughts does not differ so much logically from my present proposal of networks that represent by means of active analysis. My argument is that perceptual analysis and preparation for action, mediated by knowledge and experience, is what the brain *does*.

Remembering as an interactive activity

After presenting a paper on earlier versions of these ideas in London in 1982 I received a mild rebuke from Donald Broadbent, the great British cognitive psychologist and one of my intellectual heroes. Broadbent commented, "It is quite useful to have a clear statement of an extreme position but I wonder if I could press Professor Craik about the idea of using *only* processes in explanation, rather than a combination of processes and representations" (Broadbent in Craik, 1983). I can't remember what I stuttered at the time in answer to my hero, but now I would simply reply, "Donald, representations *are* processes!" no doubt leaving him shaking his head in bafflement and disbelief. But it must be conceded that *some* structural changes in the brain must take place to link the original event to the present experience of remembering. Here is what I wrote on this point in an earlier paper:

> Is it reasonable to characterize remembering as involving only processes or activities of mind? Surely there must be some record of the initial event that is

> compared with present processing to yield a match that underlies the experience of remembering? My view is that certainly something must change in the brain as a result of the initial experience, and this change must persist until remembering occurs. But the change in question is not simply a snapshot of the original event; it may rather be a modification of the cognitive system so that when the event recurs, the consequent processing operations are interpreted both in terms of the current event and in terms of the brain changes caused by its original occurrence. Just as perceptual learning changes the perceptual system so that subsequent stimulus patterns are processed and experienced differently, so memory encoding changes the cognitive system in such a way as to change the interpretation of a repeated event. Just as the neural correlate of perceiving is the pattern of cortical activity that occurs while we are perceiving, so the correlate of remembering is the pattern of neural activity that accompanies the experience of remembering. By this view, cognitive neuroscientists should be attempting to map patterns of neural activity to recollective experience rather than be searching for "engrams" defined as stored records of experienced events (Craik, 2002, p. 307).

The views expressed here are broadly compatible with recent statements from several current cognitive neuroscientists, almost all of whom approach the topic from the standpoint of computational modeling or neurobiology. For example, in a thoughtful article by Hasson, Chen, and Honey (2015), the authors write:

> computational modeling has shown in a variety of ways how memory and information processing can be combined in the same circuits… we emphasize that traces of past information should not be segregated from ongoing neural processes … We use the term process memory in a broad sense, to mean active traces of past information that are used by a neural circuit to process incoming information in the present moment. Furthermore, we argue for a hierarchical organization of process memory in which the time scale of memory-dependent processing gradually increases from early sensory areas to higher-order areas (p. 306).

Note that Hasson and colleagues are stressing the timescale characteristics of their organizational hierarchy. Their idea is that cortical circuits can accumulate information over time, with the times ranging from milliseconds in early sensory areas to minutes in higher-order areas.

Another relevant concept emphasized by several researchers is that the cognitive outcome of processing activity in a specific "focal" region is strongly affected by that area's interactions with other brain regions. For example, "It is the relation of the activated region to other areas that determines the cognitive operation" (McIntosh, 1999, p. 525.) McIntosh goes on to propose that:

> Although it may be the case that for the operation of working memory to occur, prefrontal cortex must be involved, the actual process is the interactions of prefrontal cortex with other brain regions. So rather than the function of prefrontal cortex, working memory may best be appreciated as one of the emergent properties of the interactions of prefrontal cortex with other brain areas" (1999, p. 526).

Bressler and Kelso (2001) also stress the interactions among brain regions as necessary for coordination; in addition, they propose that:

> Coordinated networks are dynamic structures that emerge as the cortex's adaptive "response" to the current constraints placed on its component areas (p. 32).

And again:

> The cortical system has the potential to manifest an extremely large number of coordinated networks. However, this potential is limited by several factors. Extracortical influences, originating in the external environment, the body, and subcortical brain structures, act over subcortical-cortical projection pathways to constrain activity in recipient cortical areas. In addition, cortical areas constrain each other's activity by inter-area influences acting over cortico-cortical pathways. Finally, the activity in each cortical area is constrained by its own intra-area synaptic matrix (p. 32).

They go on to conclude that information is the correlate of all these widespread interactions and constraints. Similarly, we may conclude that a specific act of remembering emerges from interactions among many brain regions, constrained by their histories of previous interpretations and also constrained (or guided) by the current external environment.

Summary and relations to other approaches

In this section I will summarize the main points made in the chapter; later chapters analyze and illustrate the same issues in greater detail. The chapter opened with the argument that rather than study the characteristics of postulated memory stores or systems based on psychological experiences and interpretations, we should focus on the representational codes themselves, their properties, and their attributes. Any final model of human memory should, of course, provide a coherent account of relevant experiences and behaviors, but it should also be consonant with the rapidly evolving evidence from neuroimaging and other measures of brain function. The focus on codes and representations usefully bypasses the difficulties encountered when a postulated psychological construct (e.g., the STM store) appears to have different characteristics (e.g., in content, capacity, and duration), depending on materials and task demands (Craik and Lockhart, 1972). Other major aspects of the present approach include the emphasis on remembering as an active constructive process, the suggestion that "secondary memory" (SM or LTM) should be thought of as a system of representations rather than an archive of memory records, and that "primary memory" (or "working memory") reflects attention paid to current perceptual inputs in combination with activated representations of existing knowledge. Within LTM, I endorsed the idea that representations are organized hierarchically, and that the episodic–semantic contrast should be regarded as representations lying on a continuum of specificity rather than as a categorical distinction. The idea is that the neural networks comprising LTM represent information at various levels of granularity from specific autobiographical instances to generalities based on these instances, and ultimately to context-free general knowledge about the world (see also McClelland et al., 1995). My further suggestion was that the representations are active analyzers of information coming bottom-up from incoming sense data and also top-down from relevant knowledge. Along with proponents of "extended mind" or "distributed cognition," I argued that the external environment is an integral part of the overall memory system, and is not simply a provider of context and cues. Finally, I made some comments on executive functions and cognitive control.

The following chapters attempt to illustrate and sharpen these very general ideas with arguments and findings from studies conducted in my laboratory and in the laboratories of other researchers. Chapters 4 and 5 focus on encoding and retrieval processes, respectively, and emphasize their similarities and complementary nature. Chapter 6 analyzes recent research on WM with a view to confirming or modifying the present suggestion that WM should be regarded as attention paid to both recent perceptual inputs and activations of pre-existing representations in LTM. One related focus of my work over the years has been the study of age-related changes in memory and attention over the adult lifespan; these studies are addressed in Chapters 7 and 8. In Chapter 9 I present a brief overview of relevant studies in the cognitive neuroscience of memory. Finally, Chapter 10 takes a big-picture approach to the main theme of the book—remembering as an activity of mind and brain.

4

Encoding and Encoding–Retrieval Interactions

In the first chapter of this book I suggested a number of basic principles of encoding and retrieval processes in human memory. First, I proposed that there are no dedicated "memory encoding processes" as such; rather, the normal processes of perception, comprehension, and thinking leave records of their operations and these records form the encoded trace of the original event. Second, from observations of amnesic patients it seems necessary to add that some mechanism of consolidation is needed to stabilize and bind the initial perceptual and conceptual processes into this encoded trace. Third, some aspects of initial processing result in a trace that is potentially highly memorable provided that the appropriate retrieval conditions are met. I also proposed that deep semantic processing was the necessary feature of such good encoding, but this conclusion is questioned in the current chapter for its completeness. Fourth, effective retrieval operations are generally considered to be those that reinstate the original encoding operations, and again this notion is examined for its adequacy. In particular, this model of encoding–retrieval interactions seems rather passive; what is the role of intentionality at encoding and retrieval?

I should also add that dividing encoding and retrieval processes into two separate chapters is clearly rather artificial in light of the many studies over the last 50 years which have shown strong interactions between these two stages of remembering. One obvious point is that the enrichment of encoding processes by elaboration and organization necessarily involves retrieval of associations and past knowledge. Additionally, participants may be "reminded" of an encoding operation at the time of retrieval with the result that such reminding processes serve to modify the original encoded representation (e.g., Hintzman, 2011; Jacoby et al., 2015). Finally, it is well established that retrieval (or test) operations also act as efficient modes of learning (Bjork, 1975; Karpicke and Roediger, 2008). These interactions will be noted at various points in the two chapters that follow.

Most accounts of human memory describe three fundamental stages: Encoding, storage, and retrieval. So how does *storage* fit into a processing model of memory? My view is that whereas encoding and retrieval processes have both cognitive and neurobiological aspects, the bridging phase of storage (while clearly necessary) has no conscious cognitive component and has therefore no part to play in a *cognitive* model. Equally obviously the biological aspects of storage are crucial

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to a complete understanding of memory and learning in humans and other animals, and will become increasingly important in constraining possible cognitive models, but in my opinion they exist at a different level of explanation from cognitive theories. It may be objected that there are many behavioral manipulations that clearly *affect* the storage phase of memory; proactive and retroactive interference processes are examples with a long history in memory research, as well as factors such as sleep (Jenkins and Dallenbach, 1924; see also Rasch and Born, 2013 for review) and (perhaps paradoxically) exercise (van Dongen et al., 2016) in the period following a learning event. However, I suggest that whereas such factors as sleep and exercise have their effects directly on consolidation or other aspects of the underlying biology of memory performance, interference factors have their effects during both encoding and retrieval phases and can therefore play a legitimate part in a cognitive model. The role of divided attention at encoding and retrieval has intrigued me for some time; its effects are interestingly difficult to pin down, and are discussed later in this chapter. The bottom line about "memory storage," however, is that it is essentially a neurobiological phenomenon and is therefore not discussed as part of a cognitive model (see also James, 1890, as discussed in Chapter 2). I should make it clear that I am not in any way *opposed* to discussing the neural correlates of memory, but the focus of my past work has been predominantly on the cognitive aspects.

Levels and after

In the first chapter I described the beginnings of the levels of processing (LOP) approach to memory and some reactions to the Craik and Lockhart article. In the present chapter I will go over some further modifications to our original ideas, and also discuss other encoding manipulations that bear some resemblance to the levels approach. This discussion then widens to address encoding processes generally and the relations between encoding and retrieval. The experiments described in this and later chapters are mostly conducted using lists of single words. This has been the tradition I have worked in, linked to the possibly questionable assumption that such materials can illustrate general principles of memory. I will also describe some experiments using pictures of objects and scenes, whose results are generally compatible with findings from word lists, so this is at least somewhat reassuring. Other researchers have studied memory for objects, numbers, actions, and real-life events, as well as memory for sentences, word passages, and stories. Most work has dealt with visual and auditory stimuli, although there are studies of taste, touch, and smell. I will stick to my story that general principles *can* emerge from laboratory studies of simple materials, but readers should be vigilant for findings that question this act of faith!

I will describe two collaborative studies from my laboratory in some detail as they show how my thinking about LOP evolved as a result of working with people from different backgrounds. The first series of experiments was carried out with Morris Moscovitch and Joan McDowd (Craik et al., 1994). Morris is a long-standing colleague and friend; Joan did her PhD work in my laboratory and then stayed on as a post-doc for a further year, and she is now a professor at the University of Missouri, Kansas City. The main goal was to explore the effects of both LOP and perceptual modality switches (e.g., audition vs. vision) on performance of implicit and explicit memory tasks. It was already known that LOP manipulations did not affect such implicit tasks as word fragment completion and word stem completion (Graf and Mandler, 1984; Jacoby and Dallas, 1981) but that these tasks were heavily dependent on the similarity of presentation modes at encoding and retrieval (Jacoby and Dallas, 1981; Roediger and Blaxton, 1987a). However, explicit memory tasks such as free recall and recognition memory are clearly sensitive to LOP manipulations (e.g., Craik and Tulving, 1975), and may also be sensitive to modality shifts between encoding and retrieval under certain conditions (Craik and Kirsner, 1974; Jacoby and Dallas, 1981).

The study by Craik et al. (1994) consisted of four experiments in which four memory retrieval tasks—word-fragment completion, word-stem completion, word-stem cued recall, and recognition memory—were assessed for their sensitivity to semantic/conceptual processing (the LOP manipulation) and also to changes in perceptual modality between presentation and test. In all cases single words were presented in the study phase, either visually (on 3” × 5” index cards in these lo-tech days!) or auditorily (simply read out loud by the experimenter). Additionally, participants carried out a mental operation on the presented word that was either shallow (e.g., Does the word contain the letter E?--MARKET) or deep (e.g., Found in China?--PAGODA). In some experiments encoding was incidental (no mention of a later memory test) and in others participants were asked to study the words for a later test. Two of the retrieval tests tapped “implicit memory” in that no mention of “memory” was made to participants who thought they were performing word-generation tasks (although performance is boosted by previous study of target words), and two tests were classified as “explicit memory” tasks in that participants were instructed to use studied words to complete the tasks. In previous work, Roediger and Blaxton (1987b) had argued that some implicit memory tests (e.g., word-fragment completion) were largely “data-driven”—that is, strongly affected by surface information—whereas other tests (e.g., free recall) were primarily “conceptually driven”—that is, sensitive to semantic information. But they added that the data-driven/conceptually driven distinction should be regarded as a continuum rather than as a dichotomy, and we found this viewpoint congenial. We therefore wondered whether surface and conceptual information would trade-off against each other—for example, would strong conceptual encoding reduce the effects of surface compatibility between encoding and test?

In the *word-fragment completion* test incomplete words were presented visually (e.g., EX- ERIM--T) and the participant's task was to complete the fragment with the first word that came to mind. *Word-stem completion* is similar, except that in this case the test consisted of presenting the first three letters of target and distractor words (e.g., EXP--). *Word-stem cued recall* is an explicit test, identical to word-stem completion except that participants were instructed that some of the word stems were from the studied words, so they should use the stems to recall words from the original list. Finally, *recognition memory* was tested by presenting studied words mixed with similar distractor words either on index cards (Experiment 1) or on a sheet (Experiment 4). So in all experiments words were studied either visually or auditorily, but the test was always visual. In this way the surface information was either same-modality (visual–visual) or cross-modality (auditory–visual). The overall design can be summarized as:

> Study: words were presented either auditorily or visually and under either shallow or deep processing conditions; Test: four different visual memory tasks were involved.

The results of this rather complex study can be described relatively easily. The effect of the conceptual manipulation was assessed simply as the benefit in test performance of the deep relative to the shallow encoding task, and the effect of the surface manipulation was taken to be the benefit of the same modality (visual–visual) combination over the different modality (auditory–visual) combination. These benefits are shown for the four different tests in Table 4.1.

The table shows that the surface modality manipulation significantly improved performance in word-fragment completion, word-stem completion, and

Table 4.1. Relative *benefits* of perceptual and conceptual manipulations on two implicit memory tasks (word-fragment completion; word-stem completion) and two explicit memory tasks (word-stem cued recall; recognition memory).

	Word-fragment completion		**Word-stem completion**		**Word-stem cued recall**		**Recognition memory**	
	A/V	**LOP**	**A/V**	**LOP**	**A/V**	**LOP**	**A/V**	**LOP**
Benefit	.10	.02	.07	−.01	.10	.12	−.01	.29
Significant?	Yes	No	Yes	No	Yes	Yes	No	Yes

Note: A/V = benefit of visual over auditory encoding; LOP = benefit of deep over shallow encoding.

Reproduced from Craik, F. I. M., Moscovitch, M., & McDowd, J. M. (1994). Contributions of surface and conceptual information to performance on implicit and explicit memory tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 20(4), 864–875. https://doi.org/10.1037/0278-7393.20.4.864 with permission from APA.

word-stem cued recall. It is also noteworthy that the size of the effect was broadly comparable across these first three tests (0.10, 0.07, and 0.10, respectively), but entirely absent for recognition memory (–0.01). We suggested that the modality effect might therefore be all or none, compared to a graded effect for the conceptual manipulation where the benefits of deep over shallow encoding were 0.02, –0.01, 0.12, and 0.29, respectively, in the four test conditions The differences between modality and LOP manipulations do not simply map on to the implicit/explicit distinction between tasks, however. LOP effects were found only in the explicit tests of word-stem cued recall and recognition memory—so conceptual effects may be limited to such tests—but modality effects were found for word-stem cued recall, an explicit test, and for the two implicit tests..

So why does the modality manipulation affect the first three tests but not recognition memory, and why does the LOP manipulation affect the explicit tests but not the implicit tests? Before attempting to answer these difficult questions let me throw in another general result from the same study; although auditory presentation and shallow encoding conditions were not as effective as visual presentations and deep encoding in certain tests, these less-favorable conditions nevertheless led to performance levels much higher than baseline conditions in every experiment. That is, cross-modal priming and recognition effects were strongly present; it was simply the case that visual encoding was even better in the first three tests. Similarly, shallow levels of processing were associated with better than baseline performance levels in all cases. One account of this result suggests that presentation of words by any means activates abstract lexical representations of the words, and that these representations play the major role in subsequent memory tests. The addition of compatible surface information or of conceptual information boosts performance further, but only in cases in which the specific test relies on processes that utilize the extra information. So the present example shows that both word-fragment and word-stem completion tests can profit from compatible visual information but not further conceptual information, recognition memory can benefit from conceptual but not further visual information, and word-stem cued recall can use both types of extra information. As a further example, the *perceptual identification test* is one in which participants attempt to identify words flashed very briefly on a screen. Words encountered recently are identified more readily than words not encountered recently (a priming effect) and words presented originally in visual form are later identified more readily than words presented auditorily originally (Jacoby and Dallas, 1981). Further, this type of priming is not sensitive to a LOP manipulation (Jacoby, 1983; Jacoby and Dallas, 1981). It thus seems that the perceptual identification test is sensitive to visual information encoded in the initial presentation, an also to abstract lexical information but not to additional semantic information. A parallel result has been found in audition; initial auditory presentations outperform visual presentations when the final test is also auditory (Jackson and Morton, 1984).

These demonstrations are captured by the construct of "transfer-appropriate processing" (Morris et al., 1977; Roediger et al., 1989), and also by the concepts of encoding specificity (Tulving and Thomson, 1973) and repetition of operations (Kolers, 1973). In essence, specific "retrieval operations" (either explicit or implicit) embody specific processing operations and these operations are facilitated when the preceding encoding event employs compatible processes. Talking about the phenomena in this way underlines the dynamic, process-oriented view of memory that I wish to emphasize in this book.

There are certainly cases in which surface feature compatibility *does* boost recognition memory (e.g., Craik and Kirsner, 1974; Geiselman and Bjork, 1980; Jacoby and Dallas, 1981), and we suggested in the Craik et al. (1994) article that such findings may reflect conditions in which perceptual processing is emphasized by the material, the context, or instructions. Examples of these conditions may include cases in which perceptual features are particularly salient, as with speakers' voices (Craik and Kirsner, 1974) or distinctive typographies (Graf and Ryan, 1990). However, perceptual effects will be limited or absent when semantic processing is emphasized at encoding and retrieval. In summary, some retrieval tasks are likely to utilize predominantly perceptual information by their inherent nature—visual recognition of colored patterns, for example, or recognition of speakers' voices—and it seems likely that the balance among perceptual, lexical, and semantic types of information can also be modified by framing the task in a particular way or by explicit instructions to attend to certain aspects of the stimuli. This whole line of argument owes a lot to Larry Jacoby's (1983) suggestions that qualitative differences in processing at encoding do not result in absolute differences in memorability, but in qualitatively different "records" whose later effectiveness will depend on the specific retrieval test encountered (see also Morris et al., 1977; Tulving and Thomson, 1973). Jacoby also made the bold statement (contrary to the "memory systems" views of Tulving and others) that "perceptual identification and recognition memory utilize different forms of information rather than reflect the operation of different memory systems" (Jacoby, 1983, p. 500). Finally, Jacoby pointed out that both perception and memory depend on the system's storage of previously encountered events and how they were processed initially; in that sense both perception and memory can be described as two aspects of a single model—a view that I strongly endorse.

This discussion thus concedes the point that LOP manipulations do not result in encoded episodes that vary in potential memorability in some absolute sense. Rather, final performance can *only* be understood after considering the interactions *between* encoding and retrieval. It is also clear that a person's goals, or experimental instructions, may serve to emphasize specific aspects of processing at both encoding and retrieval. Finally, I will reiterate the point that whereas no type of encoding is superior by itself, some encoding–retrieval combinations *are* superior to others, notably combinations that stress conceptual semantic processing (Fisher and Craik, 1977; Morris et al., 1977).

The other article that I will discuss in some detail is by Challis, Velichkovsky, and Craik (1996). At the time, Brad Challis was a postdoctoral student with Endel Tulving in Toronto. He went on to work at Tsukuba University in Japan and then went into the pharmaceutical industry. I first met Boris Velichkovsky in a basement bar in Leipzig where we expressed admiration for each other's work—and have been friends ever since! Boris now splits his time between Dresden in Germany and Moscow in Russia. He spent some months in Toronto in the 1990s, and we conducted the experiments at that time. The basic idea was to explore LOP effects on a variety of implicit and explicit memory tests to see if we could push our understanding of encoding–retrieval interactions beyond the straightforward notions of transfer-appropriate processing (TAP). For example, if we have four encoding tasks labeled a, b, c, and d, running from shallow to deeper levels of processing, and four retrieval tasks A, B, C, and D, each of which is compatible with a specific encoding task— a with A, b with B, and so on—what levels of performance might we expect to see when all four encoding tasks are combined with all four retrieval tasks?

The simplest reading of TAP suggests that each compatible encoding-retrieval combination would be associated with good performance, whereas incompatible combinations might fare no better than chance To put numbers on performance levels, this possibility predicts that a–A and b–B = 1, whereas a–C and c–A = 0. But we already know that semantic encoding paired with semantic retrieval yields higher levels of performance than a compatible shallow encoding–retrieval combination (Fisher and Craik, 1977; Morris et. al., 1977), so a more plausible formulation is that a–A = 1, b–B = 2, c–C = 3, and d–D = 4, whereas incompatible pairings = 0. However, another possibility is that a shallow retrieval task (A) might get *some* benefit from deeper encoding tasks if deeper encoding processing also incorporates shallow processing (e.g., to answer a semantic question about a word some visual processing of the word is obviously necessary). On the further reasonable assumption that a given retrieval task requires *at least* its own level of processing, this formulation predicts the pattern a–A = 1, b–A = 1, c–A = 1, and d–A = 1 and (for example) a–C = 0, b–C = 0, c–C = 3, and d–C = 3. In other words, the suggestion is that each retrieval test requires a certain level of encoded information but cannot utilize deeper information.

These ideas were tested in Experiment 1 of the study by Challis et al. (1996). All participants (young adults) studied lists of words in five encoding conditions and then received one of six retrieval tests. The encoding tasks comprised four incidental study tasks (no mention was made of a later test) and one intentional study task ("try to remember these words for a later memory test"). The four incidental tasks were designed to induce different types of processing that arguably run from shallow to deep; each task was performed on a different list of words. The tasks were:

(a) Count the number of ascending and descending letters in each word (i.e., letters such as "t" and "y" that extend above or below the main body of the word), to promote graphemic processing;
(b) Count each word's syllables, to promote phonological processing;
(c) Decide whether each word is a living object, to promote semantic processing; and
(d) Judge the relevance of each word to yourself, to promote "self-processing" (previous work had shown that self-processing is a particularly potent form of semantic encoding (Rogers et al., 1977).

The six retrieval tasks were two implicit memory tasks in which no reference was made to the encoding phase, and four explicit tests in which participants were instructed to use the information provided to recollect words from those processed earlier. The tasks included an implicit test utilizing perceptual information, *word-fragment completion*; an implicit test using conceptual information, *general knowledge questions* (e.g., "What animal did Hannibal use when crossing the Alps?"); an explicit perceptual test, *graphemic cued recall*, which provided cues resembling target words graphemically (e.g., "chopper" for the target word "copper"); an explicit conceptual test, *semantic cued recall*, in which a related word was given as a cue (e.g., "bronze" for "copper"); and, finally, *free recall* (no cues) and *recognition memory*, both explicit conceptual tests. All retrieval tasks (except free recall) also included lures or cues to non-studied words to provide a measure of baseline performance. Thus, the main measure of interest was the amount by which performance levels for words encoded earlier were above baseline (performance levels associated with non-studied words, e.g., lures in the recognition test) when that test was paired with each of the five encoding tasks. To put comparisons on a common scale we evaluated the differences between conditions using a least significant difference test (LSD) using a level of significance of 0.05. The numbers in Table 4.2(b) are thus the numbers of LSDs by which the encoding condition exceeds the baseline value for that retrieval test (see also Figure 4.1). As an example, for word-fragment completion non-studied words were correctly completed with a probability of 0.22, and target words in the letter-encoding condition, task (a) above, were completed with a probability of 0.39, giving a difference of 0.17. The LSD for word-fragment completion was 0.08, so letter encoding was at least 2 LSD units above baseline.

Several points may be made from these results. First, the implicit word fragment completion (WFC) test benefited from letter encoding, but performance was not enhanced by deeper encoding manipulations, although performance remained at the letter level. This result confirms two points—that an implicit perceptual test benefits from a compatible perceptual encoding condition, and also that these beneficial perceptual encoding operations were also present in the ostensibly deeper encoding conditions. The general knowledge test is an

Table 4.2. (a) Proportions of target words produced or recognized as a function of encoding condition and test type; (b) differences in least significant difference (LSD) units between baseline and obtained performance levels as a function of encoding condition and test type.

(a)	Test	LSD	Baseline	Letter	Syllable	Living	Intentional	Self
	WFC	.08	.22	.39	.44	.43	.41	.41
	Gen. Know	.08	.19	.22	.25	.31	.38	.41
	Graphemic CR	.07	.05	.06	.16	.23	.23	.31
	Semantic CR	.06	.05	.08	.15	.21	.23	.29
	Free recall	.06	.00	.04	.07	.17	.33	.24
	Recognition	.11	.12	.27	.51	.70	.72	.83
(b)	**Test**			**Letter**	**Syllable**	**Living**	**Intentional**	**Self**
	WFC			2	2	2	2	2
	Gen. Know			0	0	1	2	2
	Graphemic CR			0	1	2	2	3
	Semantic CR			0	1	2	3	4
	Free recall			0	1	2	5	4
	Recognition			1	3	5	5	6

Notes: WFC = word-fragment completion; Gen. Know. = general knowledge; CR = cued recall.

Reproduced from Challis, B.H., Velichkovsky, B.M., Craik, F.I.M. Levels-ofprocessing effects on a variety of memory tasks: new findings and theoretical implications. *Conscious Cogn*. 1996 Mar;5(1/2):142–64 with permission from Elsevier.

implicit *conceptual* test, and this test showed a strong LOP effect. This result speaks against the idea that all implicit tests are insensitive to LOP and suggests instead that it may be *conceptual* tests that are sensitive to a levels manipulation. The graphemic cued recall findings present a further problem; it is an explicit *perceptual* test but shows an LOP effect. Do explicit tests trump perceptual compatibility? A second experiment in the Challis et al. (1996) paper suggests they do. In this variant the same five encoding tasks were paired with the same graphemic cues at test, but in the "retrieval test" participants were simply asked to generate three words that resembled each cue word graphemically (e.g., for the cue "eagle" they might generate "bugle," "eager," and "treacle"). When these generated words were examined for inclusion of encoded words, the priming effects were present in all five cases (baseline was 0.11 and the mean for encoded words was 0.20) but with no difference across conditions. Thus, the graphemic

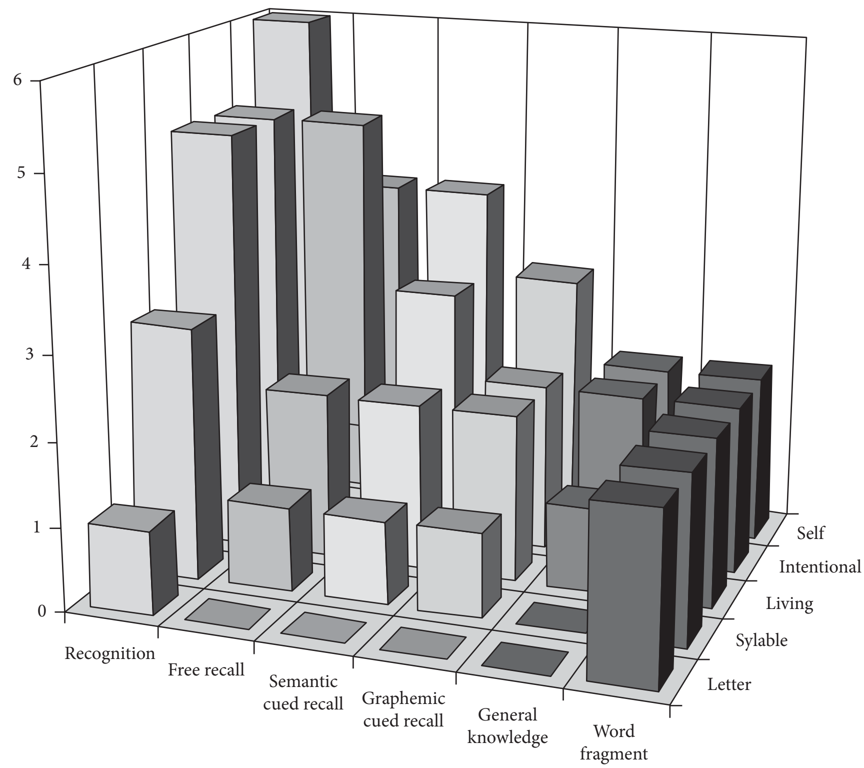

Fig. 4.1 Interaction of five levels of processing at encoding (front to back on the graph: Letter, syllable, living/non-living, intentional learning, self-processing) with six retrieval tests (from left to right on the graph: Recognition, free recall, semantic cued recall, graphemic cued recall, general knowledge, word fragment completion). The ordinate is number of least significant differences (Velichkovsky, 2002, based on data from Challis et al., 1996).

test shows no LOP effect when it is done implicitly but does show the effect when the same cues are presented in an explicit test. This makes the important point that instructions change the type of retrieval operations carried out, and that explicit retrieval operations are sensitive to LOP manipulations. The same conclusion was reached when considering the word-stem completion test in the study by Craik et al. (1994) (see Table 4.1); it functioned as an implicit or explicit test depending on instructions.

The remaining tests—semantic cued recall, free recall, and recognition—were all carried out under explicit instructions (i.e., "Use the cues to remember the prior words"), so LOP effects are expected and, indeed, found. Further, the LOP effects are *graded*, both across encoding conditions (as in the standard LOP paradigm) and across test conditions from word-fragment completion to recognition, bearing out the speculation discussed earlier in connection with the Craik et al. (1994) article, and leading to the commonsense conclusion that memory performance is a joint function of the qualitative depth and richness of encoding and the degree to which the retrieval test can utilize the specific information encoded. Table 4.2A) also shows that incidental encoding in terms of self-relevance is associated with performance levels as good as or better than those following intentional learning. This makes the interesting point that even sophisticated university students are apparently unaware of the optimal ways to encode words. It also bears on the puzzle raised by Roediger and Gallo (2001) as to why performance levels are so poor in a memory test following shallow but intentional encoding; why do intelligent participants not switch on additional semantic encoding operations, knowing that memory for the word will be tested later? (see also Craik, 1977b for a further example). The likely answer is a failure of metacognition—adult participants generally don't know the best way to remember events! The one exception to the relatively poor performance following intentional learning is with free recall, and we speculated that since free recall is sensitive to organization of the material (e.g., Tulving, 1962), people do carry out relational processing under intentional learning conditions, whereas they see no need to do so under conditions of incidental learning.

The pattern of findings shown in Table 4.2 and in Figure 4.1 thus provides strong evidence that human memory cannot be understood in terms of either encoding or retrieval operations in isolation; it is essential to consider their joint interactions. This, of course, was the important message propounded by Endel Tulving in the late 1960s and early 1970s (e.g., Tulving and Thomson, 1973), when most memory researchers were concerned with effects of learning and interference. The table also shows strong effects of TAP but qualified by findings that the combination of deep conceptual processing at encoding and retrieval is superior to shallow compatible pairings. In the original article, Challis and colleagues pointed out that if the underlying cognitive architecture was strictly modular with retrieval tasks tuned to just one type of encoded information, performance would fall off both with shallower and deeper types of encoding. This clearly does not happen, so apparently shallower levels of encoding can be used by deep retrieval tasks, albeit yielding lower levels of performance. We first concluded that these findings supported a hierarchical architecture in which lower levels are inevitably invoked *en route* to higher levels of processing, but later in the Challis et al. paper we modified this suggestion in favor of a heterarchical scheme in which representational processing operations *are* organized, but the nature of the organization is flexible depending on the person's needs and goals.

Some general principles

Towards the end of the 1970s I gave a talk at the Attention and Performance meeting outside Stockholm in which I proposed four descriptive principles of memory function stemming from the levels approach (Craik, 1977b). (Incidentally, I recently discovered a cache of 50 yellowing reprints of this chapter, proudly photocopied in 1977 but still apparently waiting hopefully for the flood of requests!). The four principles are:

Depth of processing reflects the finding that higher levels of memory performance are associated with semantic processing. This label assumes that meaningful semantic processing is "deeper" in the sense of following preliminary "shallow" sensory processing and also involving acquired schematic knowledge. In this sense, "semantic" does not refer only to linguistic semantics, but to any type of schematic knowledge acquired by the individual. So deep processing could also occur for expert wine tasters, professional hockey players and aboriginal animal trackers. A better word to capture this idea might therefore be "expertise" (Bransford et al., 1979). Depth in this sense also makes contact with current work on "deep learning" in artificial intelligence, where again regularities in scanned data gradually form meaningful constructs at higher levels in a processing hierarchy.

Elaboration of encoding refers to further rich encoding within a qualitative domain. Craik and Tulving (1975) saw this as a necessary corrective to talking about memory only in terms of depth of encoding. Elaboration provides an account of the finding that complex sentence frames (e.g., "the old man hobbled across the room and dropped the ____") are associated with higher levels of subsequent cued recall than are simple sentence frames (e.g., "he dropped the ___"), even though the frames are equally non-predictive of the target word (WATCH, in this case) provided by the complete sentence in the encoding phase. Shallower processing levels can also vary in their degrees of elaboration; for example, careful proofreading as opposed to skimming a written passage, or trying to identify the voice of an unseen speaker as opposed to listening casually to a conversation.

Congruity between an event and its context enables greater contextual integration and is also one source of greater elaboration. At retrieval, re-provision of a congruous context facilitates reconstructive retrieval beyond simply increasing the probability of a correct guess (see Mäntylä, 1986, described later). In the Craik and Tulving (1975) paper the consistently higher retention levels of words that related positively to the encoding question (e.g., animal—TIGER, as opposed to animal—MAPLE) was attributed to greater congruity (see also Schulman, 1974).

Uniqueness of the link between retrieval information and the encoded event was the fourth factor listed by Craik (1977b). The evidence came largely from a study by Moscovitch and Craik (1976) in which words in an encoding phase were associated either with a unique encoding question or shared the same encoding question with nine other words in an incidental learning paradigm. The unique questions were much more effective cues at the time of retrieval. This result is obviously an example of cue overload as described by Watkins and Watkins (1975) and the fan effect (Anderson, 1974; Anderson and Reder, 1999). I now prefer to use the label *distinctiveness* to describe these effects, a topic explored in depth by Reed Hunt in a number of influential articles (see also the collection of chapters edited by Hunt and Worthen, 2006). It is also probably necessary to distinguish distinctiveness as a function of encoding (the encoded event is clearly differentiated from other recently encoded events) from distinctiveness at retrieval (the retrieval environment has a well-differentiated linkage to the original event; Craik, 2006).

These four factors are obviously interrelated in several ways. For example, greater degrees of depth and elaboration presumably result in a more differentiated and thus distinctive encoding. Also, greater congruity between an event and its encoding context implies the involvement of past learning, and could therefore be described as a deeper encoding. The same point may be made about congruity with a person's established knowledge base (e.g., the better performance associated with "yes" vs. "no" questions in the LOP paradigm). The joint effects of congruity and distinctiveness were illustrated dramatically in a study by the Swedish cognitive psychologist Timo Mäntylä. In an incidental encoding procedure he asked participants to generate three "properties" (single descriptive words) that were appropriate personal descriptions, or subjective associations, to each of 600 target words. In a subsequent recall test, the sets of three self-generated properties were given as cues for the original words. The result of this heroic experiment (the encoding phase lasted 4.5 hours and the subsequent retrieval phase took a further 2 hours!) was that participants recalled on average 543 of the original 600 words. This very high recall rate was not due simply to the cues eliciting the targets through general knowledge, as performance was much lower when one person's generated properties were given to another person as cues (Mäntylä, 1986, Experiment 3).

Other memory-boosting procedures

The four general principles of effective memory processing just described were formulated in 1977; to what extent are they still viable 45 years later? And do they reasonably encompass *all* important principles of good memory performance at the cognitive level, or are there more factors to add in light of more recent research findings? The first point to make clearly is that the principles described in the preceding section are all concerned with *encoding*; obviously, we must add such principles of successful retrieval as TAP and adequacy of the retrieval environment. These factors are considered in a subsequent chapter, but for the moment I want to describe a number of encoding manipulations that have been shown to boost memory reliably. Many such manipulations are generally known to the average person and others have been studied in the laboratory. I will not dissect them all laboriously, but I think it may be useful to consider to what extent some of the more common procedures tap the four general principles outlined previously. It may be, for instance, that apparently different mental procedures involve common cognitive (and presumably neurophysiological) mechanisms at a deeper level of analysis. I will group the various procedures very loosely under the categories "common knowledge," "experimental findings," and "special effects."

Effects that are common knowledge

Under the rubric "common knowledge" we can say that when people intend to learn some new information or commit an event to memory they perform some deliberate mental activities, including paying attention to the material in an effortful manner; for names and numbers they may rehearse the information by repeating it mentally to themselves, they devote more time to studying the material, and may relate the new information to their well-known stock of current knowledge. Most people already know that certain kinds of information or events are naturally quite memorable—emotionally relevant events for example, and new information that is important to them personally. Even sophisticated adults vary greatly in their knowledge of how to remember effectively—their so-called metamemory abilities—and it seems clear that many people wish to improve their memories, as witnessed by the success of various self-help books and online training programs.

In the Craik and Lockhart article we made the point that "intention to learn" was not a distinct form of learning but rather indicated that the learner presumably undertook to perform more mental operations than he or she would when simply inspecting the material casually. Later memory performance would then reflect the actual operations carried out; these might include devoting more time, attention, and effort to studying the material, repeating it mentally, thinking of its semantic connotations, relating it to known information, creating a mental image of the material, or embedding it in a story. In my opinion, the variables of time, attention, and effort are simply surface indications of the underlying processes and do not by themselves signal either the qualitative nature of these processes or the probability of remembering at a later date. Although Cooper and Pantle (1967) proposed that memory was a positive function of the time devoted to studying it—the "total time hypothesis"—I argue that more time typically permits more useful processing and that memory will, indeed, benefit, but it is the amount of useful processing that is important, not time *per se*. In fact (as described in Chapter 1), Craik and Tulving showed that a difficult but shallow task took longer to perform than an easy but deep task, with the result that more time was devoted to the shallow task, but memory performance was better following the deep task (Craik and Tulving, 1975, Experiment 5).

In the same vein I argue that whereas task difficulty is often associated with good subsequent memory (see the notion of "desirable difficulty" proposed by Bjork and Bjork, 2011) again it is the nature of the underlying processing that is crucial. The relation between difficulty and recall was explored in a study by Gardiner, Craik, and Bleasdale (1973). These authors presented dictionary definitions plus the first letter of 50 low-frequency nouns for participants to retrieve. Participants were asked to say the wanted word as quickly as possible, and were given up to 60 seconds to retrieve it; if they were still unsuccessful after 60 seconds, the wanted word was supplied by the experimenter. At the end of each 15-second period participants were asked to say how close they were to retrieving the target word; ratings of 0 and 1 were used to indicate no knowledge or slight knowledge of the word, a rating of 2 indicated a strong feeling of knowledge and a response of TOT indicated a "tip-of-the-tongue" state. After all 50 words were retrieved or supplied, participants were unexpectedly asked to recall as many of the words as possible in 10 minutes. The point of the study was to see whether words retrieved with difficulty—e.g., after 15 seconds or more of trying—were recalled more successfully in the final test.

The results showed that words retrieved between 0 and 15 seconds were later recalled with a conditional probability of 0.27, whereas words retrieved between 15 and 60 seconds were recalled with a probability of 0.48. At first this result seems to be a clear piece of evidence in favor of the difficulty hypothesis, but a further result modifies the interpretation. Of the words retrieved between 15 and 60 seconds, those rated 0 or 1 ("non-TOT words") were later recalled with a probability of 0.27—the same probability as words retrieved initially between 0 and 15 seconds. Words retrieved between 15 and 60 seconds and rated 2 or TOT ("TOT words") were later recalled with a probability of 0.59, so the benefit conferred by the longer initial retrieval latency was confined to words that participants thought they knew. Words rated 0 or 1 that were retrieved "suddenly" after a long retrieval latency were recalled no better than those recalled with little or no effort. One further result was that words supplied by the experimenter were as well recalled subsequently as those actually retrieved by the participant, and such supplied words also showed the benefits of a TOT state. It therefore seems that whereas words retrieved "with difficulty" are better remembered in a subsequent recall test, the crucial factor is that the participant must be thinking of the word's semantic-associative attributes for some time before initial retrieval; given this state it does not matter whether the word was retrieved by the participant or supplied by the experimenter. Difficult initial retrieval (given a TOT state) may therefore be similar to cuing the word with a semantic orienting task in the LOP paradigm. Deep and elaborate semantic processing may be the common features associated with good memory performance.

When an individual attempts to learn material by making up stories or by relating the new information to well-known facts or incidents, this is again equivalent to deep and elaborate processing. Attempting to learn by simple repetition of words or numbers is typically not very effective as it does not usually involve either organization of the items to be learned or their integration with meaningful knowledge. Repetition may take the form of "maintenance rehearsal" (Woodward et al., 1973)—rote repetition of a small number of items using the articulatory loop (Baddeley and Hitch, 1974)—in which case later recall shows little or no benefit (Craik and Watkins, 1973; Woodward et al., 1973), although the study by Woodward and colleagues found that maintenance rehearsal did improve recognition memory. This difference between recall and recognition may reflect the proposal that recall depends primarily on inter-item elaboration and a linkage to the knowledge base, whereas recognition performance can be enhanced by intra-item integration (Mandler, 1979). A study by Thomas Nelson (1977) showed that when words were repeated for a second phonemic decision (e.g., Does the word contain an *r* sound?), two presentations led to better memory than did one presentation, and that this result held for recall, as well as recognition. A review by Greene (1987) makes it clear that repetition, in the sense of a second presentation following an interval, does improve memory, whereas rote repetition by maintenance rehearsal has little or no effect, on recall at least.

Effects studied experimentally

Turning to encoding manipulations studied experimentally, the category includes the spacing effect, the testing effect, organization, pictures and visual imagery, retrieval as encoding, schemas, and expertise, as well as the LOP effects discussed previously. Each of these topics could have a book written about them, and indeed some have! My comments will therefore be highly selective and no doubt deeply tilted towards my own preferred account. I will start with the beneficial effects associated with organization and with visual imagery, as these two sets of phenomena seem least likely to be accounted for by deeper processing in any sense.

Our memory for pictures is spectacularly good! Using pictures from magazines, selected to be vivid and not easily confusable, Shepard (1967) had participants study 612 pictures, followed immediately by 68 test pairs, one of which was a previously viewed picture. The mean percentage correct choice was 96.7%, and this contrasted with a similar test for word stimuli in which the percentage correct was 88.4%. A further study by Standing (1973) found that after studying 10,000 pictures for 5 seconds each, participants correctly recognized 66% of 160 test pairs (corrected for guessing) after 2 days. Standing concluded that our memory capacity for pictures is essentially unlimited. Further work has confirmed this general result and has also shown that memory for pictures is consistently better than for comparable words (e.g., a picture of a guitar compared to the word GUITAR). This “picture superiority effect” has received lots of attention in the last 50 years and has been interpreted in various ways. One is the “dual coding” theory proposed by the Canadian psychologist Allan Paivio—who, unusually in an academic, had won the title of “Mr Canada” in a body-building competition in his younger days. So not a man to criticize lightly! Paivio’s suggestion was that whereas words are typically represented mentally by a verbal code only, pictures of objects are encoded both in visual terms and in verbal terms, on the assumption that the viewer had named the object implicitly while perceiving it. Pictures thus have the benefit of two coded representations (Paivio, 1971). A different account was provided by Douglas Nelson (Nelson 1979; Nelson et al., 1976) in a “sensory-semantic” model. Nelson’s suggestion was that words are encoded as phonemic features, pictures are encoded as visual features, and that both feature systems then converge on a common system of semantic features. So both the word GUITAR and a picture of a guitar will give rise to the same semantic interpretation, although experimental participants will later remember which stimulus was presented by virtue of memory for either pictorial or verbal features associated with the encoded trace. Pictures are better remembered than words because of the relative richness and distinctiveness of their visual features. Nelson (1979) also suggested that “interactiveness” with and “congruity” to existing cognitive structures was a more satisfactory way to talk about the LOP concept of “depth.”

I personally prefer Nelson’s account to Paivio’s. It seems to me that pictures of complex scenes shown briefly are not readily named yet are still very well remembered. Also, Nelson et al. (1976) cited evidence that pictures are associated with good memory performance even if they are not named during the encoding process. Nelson’s notion of interactiveness suggests that pictures tap into the rich expertise provided by years of effective visual perception, again blurring the distinction between “depth of processing” and “expertise” (Bransford et al., 1979)—both terms connote the evocation of a richly interconnected semantic network. As a final word on the picture superiority effect, whereas pictures are clearly subject to the same positive effects of TAP as words are, the picture superiority effect is not simply attributable to TAP effects as it has been shown repeatedly that pictures are superior to words, even when words serve as the common recognition test materials. That is, the encoding–test combination of picture–word yields higher recognition performance than does word–word, even though the latter has better TAP credentials.

Turning to the notion of organization in human memory theory, a good place to obtain a perspective on the historical transition from “verbal learning,” based on principles of associative connections, to “memory” based on principles of information processing, is a review article written by Endel Tulving and Stephen Madigan for the *Annual Review of Psychology* in 1970. They take a refreshingly candid view of progress in the field, commenting that

> at the time when man has walked on the moon, is busily transplanting vital organs from one living body into another, and has acquired the power to blow himself off the face of the earth by the push of a button, he still thinks about his own memory processes in terms readily translatable into ancient Greek (Tulving and Madigan, 1970, p. 437).

Even the most spectacular current findings would cause Aristotle to "raise his eyebrows only for an instant" according to these trenchant critics! Some trends gained their approval, however, and the construct of organization was one of them. Two pioneers of this approach to understanding how memory works were George Mandler and Endel Tulving himself. They had been colleagues at the University of Toronto in the early 1960s, and no doubt influenced each other's thinking at that time.

According to Tulving and Madigan, Mandler believed that organization is a necessary condition for memory and that organization can take several forms—items can be arranged hierarchically, in unordered sets or in ordered serial lists. Both Mandler and Tulving stressed the importance of "subjective organization," the notion that meaning and the way that items or objects or ideas relate to each other is to a large extent determined by the individual's personal experiences. In one dramatic demonstration Mandler showed that when participants were given a set of words and asked to sort them into as many groups as made sense to them, subsequent unexpected free recall performance was a linear function of the number of categories utilized (Mandler, 1967). He also showed that participants in such experiments recalled as many words in the unexpected test as did participants who were instructed to remember the words. In line with our conclusions from the LOP experiments, "intention to learn" is not necessary for good retention; rather, it is the nature of the processes carried out, for whatever reason.

Tulving also carried out important experiments on subjective organization in the early 1960s. In one representative study he presented the same list of 16 unrelated words to be learned on 16 successive trials. After each learning trial the participant wrote down as many words as he or she could remember in any order. The word list was presented in a different order on each learning trial, but despite these differences in input order the participant's output recall orders showed progressively greater similarity as the experiment continued. That is, participants gradually grouped words together that had some meaningful relation to them personally, with the result that successive outputs showed more "subjective organization" as trials continued. The total number of words recalled also increased over successive trials, and Tulving (1962) demonstrated that the amount recalled was a function of the degree of subjective organization (SO) attained. Specifically, the increase in recall performance was proportional to log SO, where SO was calculated in terms of an information theory measure of sequential redundancy (or sequential predictability). In a further important article on this topic Sternberg and Tulving

(1977) compared various measures of subjective organization in free recall, concluding that the repetition of adjacent word pairs from trial to trial (referred to as *pair frequency*) was the most satisfactory measure.

The power of hierarchical organization was demonstrated by Bower, Clark, Lesgold, and Winzenz (1969) in a study using words from conceptual categories such as minerals. Words were presented to be learned and then recalled in any order; presentation was either blocked or random. In the blocked case, words from a single category were all presented simultaneously in a hierarchical structure with the word "minerals" at the top, branching down to "metals" and "stones"; in turn, "stones" branched down to "precious" and "masonry." Finally, appropriate subcategory members were nested under each heading—for example, sapphire, emerald, diamond, and ruby under "precious stones." Four such conceptual categories were constructed, using 112 words in all. In the randomized case, the same 112 words were scrambled and then allocated randomly to the nodes of four spatial trees, but in this case the words in each tree bore no obvious relationship to the structure. Recall differences between blocked and random conditions were dramatic; in the first three learning trials (using identical materials), participants in the random condition recalled 21, 39, and 53 words out of 112, whereas participants in the blocked condition recalled 73, 106, and 112 words in trials 1–3, respectively. Clearly, participants in the blocked condition were using their pre-existing knowledge as an organized framework to encode items appropriately and then used that knowledge again as a retrieval plan in the recall phase.

How do these studies of organization in memory relate to each other and to the principles of depth, elaboration, congruity, and distinctiveness described earlier? The key common elements appear to be meaning and structure. Words (or other remembered materials) are given a specific meaning by the context provided by other units in their organized group, and this presumably enhances their distinctiveness. This point is also made by Hunt and McDaniel (1993) in an insightful account of how both similarities and differences among encoded items are simultaneously important in many memory situations. Additionally, words clustered together typically induce a superordinate term as a group label, and this may reflect either shared knowledge (e.g., "precious stones") or personal experience (e.g., "objects on my desk"). The mental structure to be used as a retrieval plan is thus either built up idiosyncratically from the nominally "unrelated" items or already exists as organized knowledge. Such pre-existing knowledge may be considered a form of expertise, and my assumption is that knowledge/expertise boosts memory first by giving relevant incoming stimuli a highly specific interpretation, second by relating the new information to existing information (Douglas Nelson's factors of interactiveness and congruity), and third by providing the structure to facilitate retrieval. I can further suggest that the excellent memory for pictures fits this same framework by considering that our perceptual experiences over the years have given us a high degree of "perceptual expertise"—not only for visual experience, but also for audition and, to a lesser degree, for taste, touch, and smell. Greater "depth of processing" in these terms therefore refers to the specificity and interconnectedness enabled by organized past experience. A novice wine drinker may experience a wine as "red, and with a slightly musty yet pleasant taste," whereas an expert may locate it to a specific region of Burgundy and even to a specific vintage. It is clear I think that on a later unexpected memory taste test the expert would be much more likely to recognize the original wine. Many of these points were made in an excellent chapter by Bransford et al. (1979), although they regard expertise and semanticity as alternative dimensions for depth of processing. The high levels of expertise shown by a professional wine-taster, chess master, opera buff, or molecular biologist all connote rich domains of meaning that allow for levels of semantic analysis (or "afford" semantic analysis in Gibsonian terms; see Baddeley and Hitch, 2017, described in Chapter 10).

One further experimental effect that has given rise to sporadic bursts of theoretical interest for at least 100 years is the finding that *spaced practice* is associated with better learning than is massed practice. In verbal memory experiments this robust demonstration typically involves presenting items to be learned twice in a long list, with the second presentation following the first immediately or after various lags. Spaced repetitions are associated with higher levels of subsequent retention than are massed repetitions, and various accounts have been suggested as explanations of the effect. One is the notion of "encoding variability"—the idea that if the two presentations are spaced some distance apart they will be encoded somewhat differently on each occasion, thereby increasing the number or richness of cues to aid subsequent retrieval (e.g., Melton, 1970). A second idea is simply that if the same item is repeated immediately in a study trial it receives less attention and less effective processing than if the item is repeated after some time; the participant believes that the immediate item is already well learned (Greene, 1989). A third type of explanation, that appeals more to me personally, is that the second presentation reminds the learner of the first presentation, and that this implicit retrieval will occur with progressively greater difficulty at longer spacing intervals. In turn, we know that difficult study-phase retrieval is an effective encoding device, but only if the retrieval processing is semantic in nature (see the previous discussion of the study by Gardiner et al., 1973). It is, of course, entirely possible that several different mechanisms contribute to the spacing effect (Greene, 1989), but it seems to me that all major accounts boil down to some mixture of deep and elaborate processing carried out in the course of attempting to reinstate the wanted information.

Another intriguing phenomenon is known as *the self-reference effect*. Rogers et al. (1977) reported the dramatic finding that when they replicated the Craik and Tulving (1975) LOP experiments relating type of processing to subsequent retention using adjectives as the material to be remembered, but added the further question type "Does this adjective describe you?," later memory levels for the material were substantially higher than those following semantic processing.

Specifically, adjusted recall probabilities following structural, phonemic, and semantic processing of adjectives were 0.03, 0.07, and 0.13, respectively, whereas the corresponding recall level following self-processing was 0.30. This superior retention following self-reference has since been replicated by many researchers (see Challis et al., 1996 for one example). Rogers and colleagues suggested that self-reference represents a powerful and rich encoding device, and that the self-concept is a particularly well-organized and accessible schema that serves to enrich the encoded trace. Their account is therefore one of elaboration, which fits one of my four principles. Other descriptions are possible, however; for example, Klein and Kihlstrom (1986) suggested that thinking of adjectives in the context of self promoted better subjective organization among the adjectives. In a later article Klein and Loftus (1988) found evidence for both elaboration and organization and this reasonable conclusion was later endorsed by a meta-analysis conducted by Symons and Johnson (1997). My own view is that *any* well-integrated body of knowledge can serve as a framework for the efficient storage and retrieval of encoded events, provided that the events are (a) congruous with the schematic body of knowledge yet also (b) distinctive within that framework (see also Ausubel, 1962). A further example is the well-known mnemonic device of embedding unrelated nouns in "places" along the route of a well-established walk round a person's town or neighborhood—the so-called "method of loci." With practice, astonishing levels of memory performance can be achieved by this means (see, e.g., Baltes and Lindenberger, 1988). By this account the self-schema is simply one that is particularly rich, organized, and accessible. But the basic principles are those suggested previously concerning the integration of new events to a well-established body of knowledge.

I have already discussed the notion that *retrieval* can act as a powerful encoding device—provided that the retrieval processes involve semantic processing (Gardiner et al., 1973). Such findings emphasize the essential similarity between encoding and retrieval processes—a point discussed later in the book. One aspect of "retrieval-as-encoding" that has received much recent attention is the *testing effect* (Karpicke and Roediger, 2008; Roediger and Karpicke, 2006). In these and other articles the authors describe studies in which student participants learned verbal material (e.g., recall of prose passages or learning foreign vocabulary words) either by means of repeated study sessions or in a procedure in which one or more of the study sessions was replaced by a test session in which recall of the material was tested. The general finding was that testing was more beneficial than further study for delayed retention of the material, although study sessions were more beneficial for immediate testing (Roediger and Karpicke, 2006). Interestingly, the student participants were generally unaware of the superior benefits of test sessions (Karpicke and Roediger, 2008). These important results for educational practice nicely replicate and extend previous laboratory results (e.g., Tulving, 1967) and are in line with notions of desirable difficulty (Bjork and Bjork, 2011) and other studies of retrieval as encoding. In my view, the results may again be attributed to the involvement of semantic processing in the course of retrieving the wanted information. Recall the "negative recency effect" (Craik, 1970) in which it was found that words retrieved with little effort and using phonemic cues from the last few items in a free recall list were *least* well recalled in a subsequent "final free recall" test.

Special effects

In overview, special effects include the generation effect, the production effect, and subject-performed tasks. No doubt there are further examples, but a consideration of these very different effects will yield some further ideas of what makes for good memory performance. Can they all be subsumed under the preceding four principles? I will argue "yes—in general," although the principles will have to be modified and qualified in the process.

The generation effect (Jacoby, 1978; Slamecka and Graf, 1978) describes the memory advantage associated with generating an incomplete word, often accompanied by a helpful cue, compared to reading the complete word. Thus, completing the word "slow" from the combination fast—S_ _W results in better subsequent memory than simply reading the combination fast—SLOW. The cognitive effort required to generate the incomplete words seems trivial, yet the benefit is highly reliable. My first reaction was to attribute this effect to the greater involvement of semantic/conceptual information necessary to identify the word in the generate condition—to retrieve it from semantic memory, as it were. However, subsequent work makes the likely explanation somewhat more complex. First, in a beautiful demonstration, Jacoby (1983) found a crossover interaction between reading or generating a word and whether the test was explicit (recognition memory) or implicit (perceptual identification of words in a very brief visual display). He asked participants to read words aloud (e.g., "cold") in three conditions: With no helpful context (xxx–"cold"); with an antonym context (hot–"cold"); or after generating them from provided antonyms (hot–?). For these three conditions—*no context*, *context*, and *generation*—subsequent values of recognition memory were 0.56, 0.72, and 0.78, respectively, whereas probabilities of perceptual identification were 0.82, 0.76, and 0.67, respectively. More conceptually driven processing (generation) benefited recognition, but more data-driven processing (no context) benefited perceptual identification (Jacoby, 1983, Experiment 2). Rather than considering implicit and explicit memory to reflect different memory systems, Jacoby argued that they are sensitive to different types of initial processing—conceptual for explicit and perceptual for implicit. This account was echoed in the later study by Craik et al. (1994) described earlier. Jacoby did find that generation conveyed a small benefit to the implicit test as well, and suggested that thinking of the word might elicit some covert visual processing that helped later identification. Another possibility, presumably, is priming lexical representations of the words themselves.

In a nice study from my own laboratory, my graduate student Betty Glisky (who went on to Chair the Department of Psychology at the University of Arizona) and my post-doc Jan Rabinowitz (who was subsequently on the faculty at Barnard College before very sadly dying at a shockingly young age) suggested that generation during the encoding phase had two consequences: Conceptual and perceptual. At the time of the test they asked participants to again generate incomplete words (e.g., AL_OHO_) as part of the recognition test for previously presented words, and found that this further generation process during the retrieval phase did boost performance, but only if the words had been generated in exactly the same way at encoding. Their conclusion was therefore that generation at encoding involved conceptual processing, which benefited subsequent memory regardless of the type of test, and also involved specific processing of surface features which, in line with notions of TAP, gave a *further* boost to recognition—but only if the same operations were invoked in the retrieval phase (Glisky and Rabinowitz, 1985). A very similar conclusion was reached by another former student of mine, John Gardiner, in a study exploring the effects of generation on subsequent recognition and word-fragment completion (Gardiner, 1988). Participants either read complete words or generated them from cues, for example *Political Killer:* ASSA_ _ _N. In different experiments the later word-fragment completion test provided either identical fragments to those at study or a different fragment, e.g., A_ _ A _ _ IN. The finding was that generation boosted word recognition reliably by an average of 16% and also boosted word-fragment completion by about 10%, but again *only* when the word fragments were identical at study and test.

Overall then, this consistent pattern of results strongly suggests that when individuals read or generate words by various means (or, indeed, hear them, read them in Braille, or view them in sign language) specific processes are necessarily run off to identify and comprehend the words. Performance levels on a subsequent memory test then depend on the compatibility of encoding processing with the retrieval processes necessary for the specific retrieval test. Generation at encoding appears to involve semantic processing which benefits later memory, regardless of how the word is presented (as long as the word is recognized at retrieval), but, in addition, generation at encoding involves specific surface operations that confer a *further* benefit, but only when the same surface operations are repeated. Roddy Roediger has an excellent chapter discussing the generation effect in these terms (Roediger et al., 1989), and in a more recent meta-analysis Sharon Bertsch and colleagues confirmed that robust nature of the effect and discuss various factors that affect its size (Bertsch et al., 2007).

The production effect (Gathercole and Conway, 1988; MacLeod et al., 2010) refers to the finding that saying a word aloud is better for subsequent memory than reading it silently. MacLeod and colleagues showed that silent mouthing of words in the study phase also conveyed a benefit to subsequent recognition, but it is not the case that *any* response is beneficial; for example, pressing a response button to half of the words on a list gave no advantage in the later test. The article makes the important point that the production effect is found *only* in a mixed-list procedure, in which half of the words are vocalized and the other half are read silently. This finding led MacLeod and others to conclude that the vocalized words are *distinctive* relative to words read silently. To some degree participants remember saying the word at the time of retrieval and this enhances memory performance. This conclusion was also reached in a prior study by Dodson and Schacter (2001), who found that lures related to target words were better rejected in a recognition test when words were said aloud at the time of encoding. The authors suggested that participants employed a distinctiveness heuristic at the time of retrieval in which they (mentally) demanded access to distinctive "say" information in order to judge a test word as "old." If no "say" information is found, the item is rejected: "If I had said it I would have remembered it" (Dodson and Schacter, 2001, p. 157).

Further studies of this general phenomenon revealed that other operations on the words in the study phase also produced benefits to subsequent recognition—these operations included mouthing the words silently, spelling their letters, writing, and typing the words—although vocalization was the strongest effect (Forrin et al., 2012). This research group also found a benefit—although again not so great—if words at encoding were spoken aloud by another person (MacLeod, 2011). So the message from these studies appears to be that any enhancement of the written word improves subsequent memory, with the degree of improvement depending on the distinctiveness conferred on target items compared to lures in a recognition test. In terms of the principles describe earlier, these "production effects" may be understood as instances of elaboration at encoding conferring enhanced distinctiveness at retrieval, provided that retrieval processing taps qualitatively similar types of information (see also Rabinowitz and Craik, 1986).

Subject-performed tasks

Another encoding manipulation that confers a substantial benefit to later memory performance consists of carrying out motor actions in response to simple commands. Thus, participants either learn a list of commands such as "touch your nose," "move the book," and "tear the paper" by reading them only, or by actually performing the actions—so-called "subject-performed tasks" or SPTs (Cohen, 1981; Engelkamp and Cohen, 1991). Although there is little or no extra effort in carrying out the actions, the effect on subsequent memory performance is substantial. Figure 4.2 shows some nice results by Rönnlund et al. (2003) using participants from the Swedish Betula Project. Cued recall levels of SPTs over VTs ("verbal tasks") are boosted by a probability increment of around 0.2, which corresponds

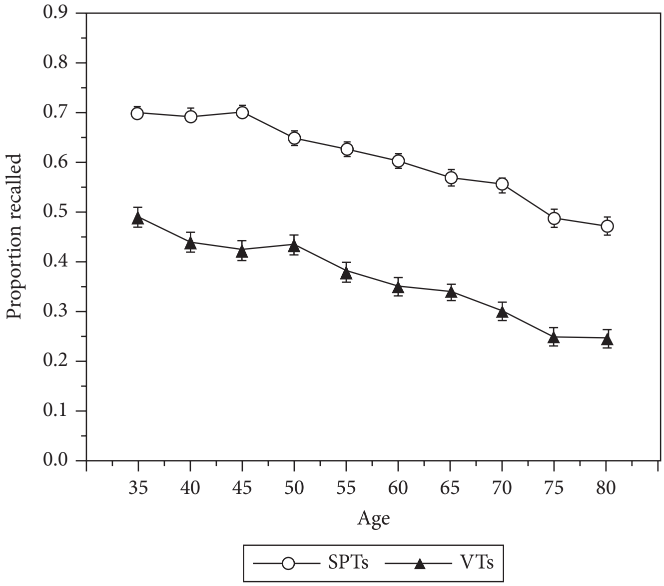

Fig. 4.2 Cued recall performance as a function of age and information encoded as subject-performed tasks (SPTs) or verbal tasks (VTs).

Reproduced from Rönnlund, M., Nyberg, L., Bäckman, L., & Nilsson, L.-G. (2003). Recall of Subject-Performed Tasks, Verbal Tasks, and Cognitive Activities Across the Adult Life Span: Parallel Age-Related Deficits. *Aging, Neuropsychology, and Cognition*, 10(3), 182–201. https://doi.org/10.1076/anec.10.3.182.16449 with permission from Taylor and Francis.

to a 40% increase in items recalled for participants aged 35 years, and an 80% increase for participants aged 75 and 80 years. It seems likely that the SPT effect reflects *both* a further instance of enhanced conceptual processing and the additional motoric information associated with carrying out the actions. Evidence for the former point was provided by Zimmer and Engelkamp (1999), who showed that when the SPT paradigm was combined with a LOP manipulation, the LOP effect was substantially reduced in the SPT condition versus the VT condition (simply reading and learning a list of commands). The authors concluded that SPTs involve access to meaning in order to perform the task, and that this conceptual processing boosts memory when combined with a shallow VT ask, but is redundant with a deep VT task. Evidence for the point that SPTs confer helpful motoric information was provided by Saltz and Donnenwerth-Nolan (1981). In their study, participants learned sentences by adding motoric enactment (SPTs), adding visual imagery, or simply as verbal statements. Sentence recall was boosted by the addition of either motoric or visual imagery, and the modality specificity of each treatment was illustrated by the disruptive effects of a motor interference task on motoric imagery but not visual imagery, and the parallel disruptive effects of visual interference task on visual but not motoric imagery. A further piece of evidence in favor of the motoric imagery basis of SPTs was produced by Nilsson and colleagues (2000). They measured brain activity (positron emission tomography) during retrieval of brief verbal commands following encoding that involved either enacting the command, imagining enacting the command without actually performing it, or silently rehearsing the verbal material. The results showed that activity in the right motor cortex was greatest following encoding enactment, intermediate following imaginary enactment, and least following verbal rehearsal.

Reduced encoding effectiveness: divided attention

In this section I will briefly discuss work from my laboratory exploring the effects of carrying out a secondary task while also attempting to encode or retrieve information in memory. This topic has obvious real-life implications—the value (or otherwise!) of studying while the TV is on, for example. In the Craik and Lockhart (1972) article, and also in a chapter by Craik and Byrd (1982), we stressed the close interactions between memory and attention. The quality of encoding was assumed to reflect the amount of processing resources devoted to the encoding operations, and in my view "processing resources" are equivalent to attention paid to the task. It therefore follows that when attention is divided between a memory encoding task and some concurrent secondary task, divided attention (DA) should result in less effective encoding processes and a reduction in subsequent memory relative to conditions of full attention. This conclusion is supported by the results of previous experiments (e.g., Baddeley et al., 1984; Murdock, 1965), although the underlying mechanisms are still poorly understood. In my own laboratory we favored the notion that when attention is withdrawn the resulting encoded representations are less deeply semantic and less elaborate. This description is given some credibility by the finding that DA at encoding is associated with reduced activation in left inferior prefrontal areas (Shallice et al., 1994)—the same areas that are associated with meaningful processing (Kapur et al., 1994; Petersen and Fiez, 1993).

I carried out a series of studies to explore these issues, many in collaboration with my friend and colleague Moshe Naveh-Benjamin. Moshe was a regular summer visitor to Toronto from his home base in Beer Sheva, Israel; he now works at the University of Missouri at Columbia. In the main study to be reported here (Craik et al., 1996) we also collaborated with Richard Govoni who was an older (and very creative) undergraduate at the time, and with my graduate student Nicole Anderson (now my colleague at the Rotman Institute). The general method we used was to present single words or word pairs auditorily for the participant to learn, either under full attention (FA) or divided attention (DA) conditions. In the latter conditions the secondary task consisted of a continuous visual reaction-time task (see Craik et al., 1996, for fuller details). This encoding phase was then followed by a test of recall or recognition.

The basic results were that DA conditions resulted in a substantial drop in memory performance when the secondary task was performed during encoding. Performance on the visual reaction time (RT) task also slowed somewhat under DA conditions relative to single task performance. We also found that the trade-off between encoding goodness and RT performance was under conscious control—participants could deliberately maintain good performance on one task at the expense of performance on the other task under DA conditions. This very understandable pattern of results was not replicated when the secondary task was performed during retrieval, however. In this case DA reduced memory performance only slightly, whereas RT performance was greatly impaired. Also, unlike DA at encoding, shifts in emphasis between memory retrieval and the RT task had virtually no effect on performance of the memory task (although performance on the RT task was slowed when memory was emphasized). The pattern of DA at retrieval therefore suggests that memory accuracy is protected in a somewhat automatic way, perhaps at the expense of retrieval latency (Baddeley et al., 1984). One speculative possibility is that memory retrieval is very public; participants are embarrassed if they fail to retrieve many words, whereas RT performance impairments are much less apparent. This issue is taken up again in Chapter 10. But the main conclusion we drew from these experiments is that good encoding requires attentional resources, and if these resources are withdrawn there is a reduction in the depth and elaboration of the encoding processes carried out.

We also explored a shared time model of memory and RT, asking whether under DA conditions memory performance is simply a function of the time "provided" by slowing of the concurrent visual task. For example, if mean RT for the visual task performed alone is 500 msec and the value rises to 800 msec under dual-task conditions at encoding, is the observed level of memory performance predicted by the "available" time difference of 300 msec? We investigated this possibility by first tracing out a function relating encoding time to memory performance under conditions of FA. So each participant recalled words from a 15-item list after four different rates of presentation: 0.75 seconds, 1.50 seconds, 2.50 seconds, and 4.00 seconds per word. The increasing levels of recall from 0.75 seconds to 4.00 seconds thus allowed us to plot a calibration function relating encoding time per word to recall performance. Under dual-task conditions words were presented at a 4-second rate, with the encoding phase for 15 words thus lasting 60 seconds. To return to the example of the visual RT task taking 800 msec under dual-task conditions, 800 msec per stimulus means that 75 responses were made during the 60-second encoding phase (60 s/800 msec). If each response contributes 300 msec to encoding processes then 75 × 300 msec = 22.5 seconds is supposedly available for encoding. The value of 22.5 seconds total encoding time can then be entered into the calibration curve to check the validity of the shared time model.

The results from two experiments are shown in Figure 4.3. Experiment 1 was the experiment described above in which encoding was carried out under dual-task

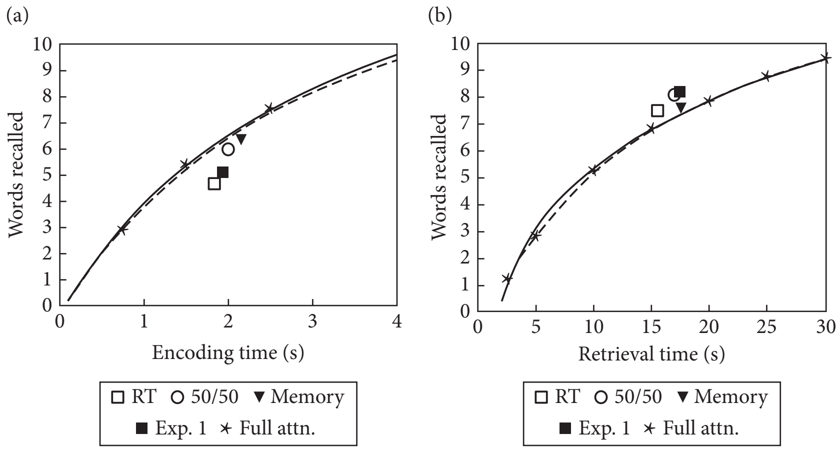

Fig. 4.3 Shared time model. In both figures the solid line is the best-fit function relating words recalled to encoding time under full attention. (a) also shows free recall values under divided attention conditions for Experiment 1 and for three conditions of emphasis in Experiment 2. (b) shows cued recall values for three conditions of emphasis in Experiment 3. Craik et al. (1996, Experiments 1–3).

Reproduced from Craik, F. I. M., Govoni, R., Naveh-Benjamin, M., & Anderson, N. D. (1996). The effects of divided attention on encoding and retrieval processes in human memory. *Journal of Experimental Psychology: General*, 125(2), 159–180. https://doi.org/10.1037.0096-3445.125.2.159 with permission from APA.

conditions. The figure shows that recall is somewhat less than that predicted by the calibration curve. Experiment 2 was an exact replication carried out under three conditions of emphasis; participants were either told to emphasize recall performance (memory), to emphasize both tasks equally (50/50), or to emphasize good performance of the secondary RT task. The upper figure shows that the first two conditions fit the calibration curve quite well but that emphasis on the RT task dropped recall performance well beneath the calibration curve. In the original article we suggested that the executive control of division of attention between the two tasks may itself require attentional resources that are therefore not available for memory encoding. The lower figure shows similar results from Experiment 3, which involved paired-associate encoding followed by cued recall—again under three conditions of emphasis.

Further experiments in the series yielded the same pattern of results. Thus, overall, we can conclude that division of attention reduces the adequacy of encoding operations and that memory performance suffers as a result. Further, the observed level of subsequent recall or recognition is a function of the time left over from performing the secondary task, with the rider that some dual-task conditions may also require processing resources to manage the division of attention.

Effects of reduced resources at encoding: Processing or consolidation?

More experiments involving the effects of DA on memory followed from an informal observation in my laboratory; the experimental findings also bequeath an interesting and unresolved question. The original observation was made several decades ago when we were following up the original LOP experiments reported by Craik and Tulving (1975). In the experiment in question, participants were again making semantic decisions about words in an incidental learning paradigm and were later unexpectedly asked to recall the words. My research assistant reported that one undergraduate was quite intoxicated when he performed the experiment; he had apparently just finished a set of exams, had a few beers with friends, but then responsibly remembered his appointment in the psych lab. We discounted his data but scored them anyway to see if his performance differed from his (presumably!) sober counterparts. The basic observation was that he performed the initial semantic classification tasks perfectly, but his subsequent memory performance was much poorer than average. Our position at that time was that memory reflected the processes carried out at encoding, so this observation was in apparent conflict with that dictum. We were sufficiently intrigued to recruit a further dozen volunteers from the local pub; the criterion was that they had drunk at least three pints of beer before participation. Results from this further (pre-research ethics boards!) group confirmed the original observation—performance on the initial classification task was entirely normal but subsequent memory performance was substantially impaired.

My graduate student Jill Kester (who also published later under her married name of Jill Locantore) and I took up the problem some years later, using the more respectable manipulation of dual-task procedures rather than intoxication. The most obvious solution to the puzzle was that impaired participants could perfectly well answer general questions about words or other stimuli but would not process them so richly and deeply. So the tack taken by Jill Kester and me (and subsequently published in a book chapter; Craik and Kester, 2000) was to equate initial processing as far as possible under conditions of full and divided attention. Assuming we could do this, and that division of attention did, in fact, reduce elaboration richness, the question was whether the relation between elaboration and subsequent memory would look like Figure 4.4a or Figure 4.4b. That is, would lower elaboration under DA conditions yield an "appropriate" level of memory, continuous with performance under FA conditions (Figure 4.4a), or would memory be lower following DA at encoding despite equivalent levels of elaboration.

In our first experiment we presented 70 noun pairs to participants, asked them to form a meaningful connection between the words and then rate the achieved meaningfulness 0–5, where 0 meant no meaningful connection and 5 meant a strongly meaningful association. Two groups performed this task, one under

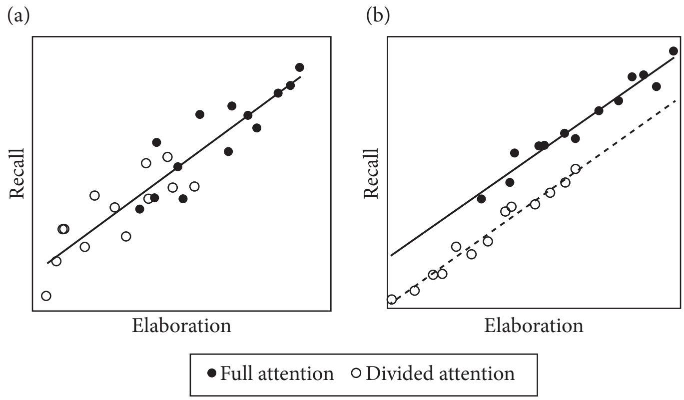

Fig. 4.4. Two hypothetical functions relating recall to degree of elaboration. In (a), divided attention reduces elaboration, but recall is a function of the degree of elaboration achieved. In (b), divided attention also reduces elaboration, but recall is further reduced relative to the full attention function (Craik and Kester, 2000).

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single task conditions and the other while concurrently monitoring a long string of digits for runs of three successive odd digits (e.g., 353,591,719). After this encoding phase participants were given an unexpected cued recall test followed by a recognition test for the second words in each pair. The result was that at each level of elaboration (0–5) the FA group had superior levels of both cued recall and recognition memory; the average differences were 0.29 and 0.18, respectively. This result thus bore out our earlier observations on mildly intoxicated participants—that impaired encoding operations are associated with impaired memory. The experimental findings suggested that this is so even when the richness and meaningfulness of encoding are equated in the two encoding conditions.

We tested the same idea in a somewhat more rigorous second experiment (Craik and Kester, 2000, Experiment 2) in which the degrees of elaboration were assessed by independent judges. In this study word pairs were again presented to participants under conditions of FA and DA. They were told it was a test of creativity and that they should make up as rich and meaningful a sentence as possible to relate the two nouns. In this case each word pair was presented auditorily followed by 6 seconds of silence to enable participants to compose a sentence in their heads. Following a beep, participants then spoke their sentences into a tape recorder. The secondary task was again the three-odd-digits task, but this time presented visually. DA was a within-subject variable in this experiment, with half of the participants performing the DA task first. Following both encoding phases participants were given the first words from each original pair and asked to recall its associated word. Finally, the generated sentences were transcribed and rated for degree of elaboration (0–4) by three judges who were blind to encoding condition. The results are shown in Figure 4.5; DA at encoding clearly results in an impairment of recall despite good evidence that the depth and richness of initial processing was equivalent under FA and DA.

This surprising result seems to leave two general avenues open for further exploration. First, DA at encoding possibly *does* reduce the depth and elaboration of current processing, but in less obvious ways—for example by reducing the strength of subjective organization among items to be remembered, or perhaps by reducing the richness of the evoked visual imagery. The second possibility is that DA leaves the ability to elaborate relatively intact but impairs the encoded integration of items with their current context. This second possibility fits well with the account of consolidation proposed in 2019 by Yonelinas, Ranganath, Ekstrom, and Wiltgen. They suggested that events are fixed more firmly in memory (i.e., consolidated) by being bound to their contexts of occurrence in the hippocampus at the time of perception. It seems possible that division of attention during encoding could impair this binding process. Alternatively, other more classical accounts of consolidation (e.g., Josselyn et al., 2015; Frankland and Bontempi, 2005) may also provide an explanation.

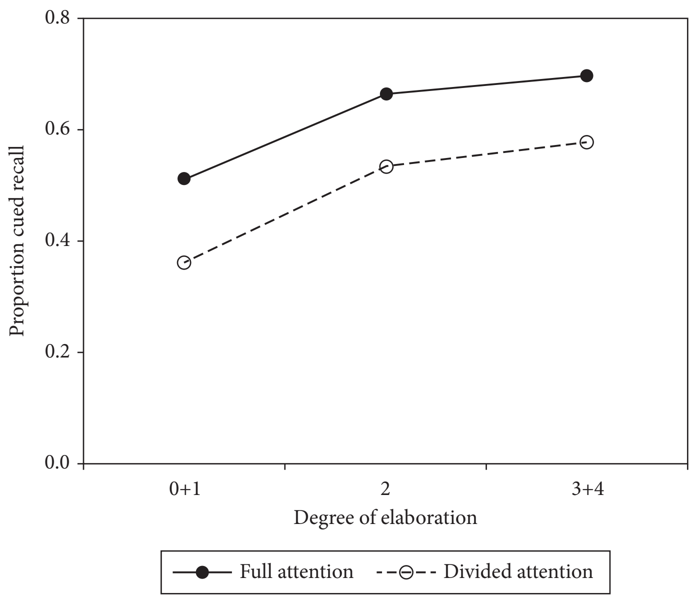

Fig. 4.5 Proportions of cued recall as a function of judged degree of elaboration. Recall following divided attention at encoding is reduced relative to full attention even when degree of elaboration is equated (Craik and Kester, 2000, Experiment 2).

Reproduced from Tulving, E. (Ed.). (2000). *Memory, consciousness, and the brain: The Tallinn Conference*. pp 38–51. Psychology Press with permission from Taylor and Francis Group.

In order to follow up on this interesting loose end it may be useful to switch from purely behavioral experiments to neuroscience methods. For example, a repetition of the study with Kester carried out in the functional magnetic resonance imaging scanner could reveal whether DA at encoding (after elaboration was equated) was associated with a differential decrease in activation in inferior left prefrontal regions (suggesting reduced depth of encoding), or with a decrease in the neural correlates of consolidation, perhaps in the strength of hippocampal activation (Yonelinas et al., 2019). The second result could be particularly interesting and might lead to work relating measures of processing resource depletion to later memory. From a theoretical point of view, my assumption has always been that differences in depth of processing relate rather directly to corresponding differences in memory performance. But this suggested work could illustrate the plausible point that LOP may interact with available processing resources, or possibly with levels of arousal, to determine the potential for later memory. A related point concerns possible interactions between resource availability and types of processing; for example, it seems possible that more "controlled" processing operations (as opposed to relatively automatic operations) would be differentially vulnerable to reductions in available processing resources. Apart from DA and intoxication there are other conditions such as fatigue, sleep deprivation, and some drug effects (Curran, 1991) that appear to yield the same pattern of results. As a final conjecture, some forms of clinical amnesia may reflect a similar mechanism, given that their memory deficits have no obvious correlates during initial perception and comprehension.

A co-author's doubts

In a letter written to me in 1971, my senior colleague, friend, mentor, and sometime tennis partner Endel Tulving commented on our preliminary notions of levels of processing: "I predict a bright future for these ideas … ," he wrote encouragingly, "… at least some of them." This reservation may have reflected his native Estonian caution, but of course Endel had his own views, some of them quite firmly held, and the upstart LOP notions clearly fitted well with some, but not all, of his core beliefs. One idea that did *not* fit the Tulving world view was the point that "the memory trace can be understood as a byproduct of perceptual analysis" (Craik and Lockhart, 1972), a point repeated in the statement that "the central idea is that memory is not a separate faculty in any sense, but is a reflection of processing carried out primarily for the purposes of perception and comprehension" (Craik, 1983, p. 343), and again "By this view there is no self-contained 'memory module': rather, memory is a byproduct of the general processes of perception and comprehension" (Craik, 1999, p. 101).

Tulving took me gently, but firmly, to task on this issue in a chapter he wrote for my Festschrift; a volume ironically subtitled "Essays in *Honour* of Fergus Craik". His view is that "encoding is the process that converts the event-information (provided by perception or thought) into an engram (memory trace)" (Tulving, 2001, p. 12). He pointed to several examples showing that a process of "memory encoding" is needed, in addition to perception and comprehension. I discuss these ideas here as they directly address the issues covered in the present chapter, and it may be of general interest to explore how far the LOP framework can or cannot accommodate Tulving's alternative position. One of his points concerned the interesting phenomenon that if the name of a famous person is unexpectedly introduced into a free recall list in the encoding phase, the name is very well recalled, but the item preceding the name is poorly recalled relative to control items. "Why?" asks Tulving rhetorically. "Was the item not *perceived*?" A second example illustrates the opposite effect—that novel items in a list or elsewhere are particularly *well* remembered. I would account for these examples by appealing to the roles of attention and elaboration in memory encoding; if attention is diverted elaboration will suffer and if attention is attracted to an item, elaboration and subsequent recall will benefit. Tulving also cited the example of false recalls of non-presented words in the DRM (Deese–Roediger–McDermott) paradigm (Roediger and McDermott, 1995); for example, the non-presented word "sleep" will often be recalled from a presented list containing words like "bed, pillow and dream." "How can this be if they were not *perceived*?" asks Tulving. Here I would say that retrieval processes are constructive as well as reconstructive, and so they "retrieve" the non-presented word because it is highly probable in the current retrieval context. It is also possible, of course, that experimental participants may generate such key words as "sleep" implicitly while processing related words during the encoding phase, and so words *are* perceived at input, albeit subjectively.

Two further examples give me more trouble, however. One is the finding that some drugs, notably benzodiazepines, seriously impair subsequent recall of events, despite the fact that they were apparently well perceived at the time of presentation (Curran, 1991). I described a similar phenomenon with alcoholic intoxication earlier in this chapter; also, aging and DA may impair memory for similar reasons. One possibility is that these effects simply reflect a reduction in depth and/or elaboration of the encoded events, although the results of the Kester experiment described earlier throw some doubt on this line of argument. The second possibility is to acknowledge the role of some further non-cognitive physiological process ("consolidation" for short) that is necessary to convert the ongoing cognitive processes into the "memory trace." A further example appears to *require* the involvement of processes beyond those at the cognitive level. This is the point that the memory impairment associated with drugs or aging is greatly amplified in cases of anterograde amnesia, extremely so in the case of H.M., the amnesic patient whose perception and comprehension were apparently normal yet whose episodic memory levels were close to zero (Scoville and Milner, 1957). In this case it seems clear that some non-cognitive mechanism is impaired, and that neurophysiological methods will be required to elucidate the situation.

Tulving's critique goes on to cite such methods—functional neuroimaging in particular—and relevant work is described in Chapter 9. It has been shown that a region of the inferior left prefrontal cortex (PFC) is activated when an event is encoded deeply and meaningfully (Kapur et al., 1994), but it is unclear whether the activation signals depth of processing or some post-cognitive binding mechanism. Tulving's point here is that he feels such encoding-related activity is more reasonably ascribed to *encoding* as such, rather than to perception, or even perception plus comprehension. As discussed in Chapter 9, the left PFC activation level is reduced when the necessity to process meaning is reduced, and is also reduced by conditions (e.g., aging, DA) that plausibly reduce the depth and elaboration of processing and that are reliably associated with a reduction in subsequent memory performance. The activation thus seems to be associated with the qualitative nature of cognitive experience rather than with a cognitively silent mechanism of consolidation. Even if this point is fully accepted, of course, it does not rule out the likelihood that some *other* neural mechanism is needed to "fix" the products of cognitive processing in the brain in a way that will support later retrieval. It may be possible to attribute the relatively poor memory associated with such "functional" impairments as fatigue, sleep loss, DA, and aging to impaired cognitive processing, but when it comes to the more obviously "organic" impairments associated with clinical amnesia it seems necessary to agree that some cognitively silent mechanism of consolidation is necessary. So if Tulving's criticism boils down to "the full range of processes necessary for the formation of memory traces involve more than the cognitive processes of perception and comprehension" I am inclined to agree with him. But nevertheless I still stick stubbornly to the position that *at the cognitive level* there are no separate processes devoted exclusively to memory encoding, and that the normal processes of perception and comprehension are all we need to ensure good later memory performance.

Principles of good encoding revisited

In light of the preceding discussion I can set out again my suggested principles of good memory encoding in somewhat modified terms. First, I stand by *depth of processing* as a major correlate of memory performance in the sense of progressively greater involvement of meaning and expertise in the analysis of incoming information. I also still believe that the amount of attention devoted to this analysis will determine how deeply information is processed and registered consciously, running from simple knowledge that a stimulus is present, through analysis of its sensory and basic features (e.g., color, brightness, size, voice quality, loudness) to semantic identification, classification, integration, and enrichment by the construction of implications and relations to both current knowledge and to episodic memories of previous similar occurrences. So attention is necessary for a full analysis of incoming information, but this relation is modified by the *congruity* of the information with processing systems. Thus, a highly familiar, well-practiced, or expected event will be processed deeply with relatively little need for attention because the pass-mark criteria of the various levels of analysis have been set to lenient levels, following Treisman's (1964b) account. It is also worth repeating that "semantic" in this context is not confined to linguistic analysis, but pertains to all knowledge domains, with the implication that the terms depth and expertise are largely synonymous.

Elaboration is also a salient characteristic of good encoding but now, while semantic elaboration may still be the dominant form, I would also emphasize elaboration by other means. Thus, we have seen that additional motor information (SPTs), visual information (the picture superiority effect), and voice information (the production effect) can boost later memory. Again, it seems likely that the effectiveness of these additional sensory–motor sources of information will depend on the individual's expert experience with that information (e.g., wine tasters, professional athletes, Braille readers). The richness of elaboration will also depend on the *congruity* of the processed information with existing organized knowledge systems. Thus, memory for a novel painting will depend on the elaboration provided by the meaningfulness of its subject matter, how much the viewer knows about other paintings by that artist, and so on.

The *distinctiveness* of an encoded event is clearly a further major factor determining memorability (Hunt and McDaniel, 1993; Hunt and Worthen, 2006). To extend my previous description slightly, it seems necessary to distinguish distinctiveness of an item relative to other recently encoded items ("episodic distinctiveness" as it were) from distinctiveness of the item relative to relevant existing knowledge ("semantic distinctiveness"). Overall, it is important to bear in mind that distinctiveness is a relative term—an encoded event is always more or less distinctive *relative* to some relevant background (Jacoby and Craik, 1979).

Beyond memory for individual events, attention must be paid to the links among encoded events (e.g., subjective organization) and to the congruity of the new event to the richness, integration, and accessibility of existing knowledge structures. That is, *organization* is clearly another major factor in memorability. No doubt there are other factors. *Emotionality* is a case in point; emotional events are typically very well remembered. However, whereas the degree of emotion experienced is, to some large extent, cognitive, I feel that the underlying mechanisms are substantially neurophysiological in nature and so are in a different class from the cognitive mechanisms discussed in this chapter. The other major principle that was neglected in our original formulations is that the effectiveness of any encoding operation can only be fully assessed in relation to the retrieval operations engaged at the time of test. How retrieval may be viewed in a LOP framework is the topic of the next chapter.

5

Retrieval Processes

Retrieval is a crucial, if poorly understood, component of human memory processes. The salience of retrieval was emphasized by such classical writers as James (1890) and Bartlett (1932), and has also been stressed by a number of recent investigators. My colleague Bob Lockhart has even gone so far as to suggest that the *only* distinct memory process is retrieval (Lockhart, 2001, p. 101). At first this seems like a strong claim, but it makes good sense when viewed in the context of the levels of processing (LOP) arguments suggesting that memory encoding processes are nothing more than the normal processes of perceiving and understanding. A similar point of view was spelled out by Roddy Roediger, who wrote:

> Encoding and storage are necessary but certainly not sufficient conditions for remembering: retrieval processes are critical to convert these latent traces to conscious mental experience of the past (2000, p. 58).

And, in the same vein, Morris Moscovitch drew the distinction between the *engram*, the physiological basis of stored information, and *memory*, its appearance in experience or behavior:

> The view that memory does not exist until it is revealed in behavior or thought, conceives of memory, not as a free-standing entity, but as linked to a process of recovery and emerging from it. Memory is the product of a process of recovery (an act of memory) rather than an entity which exists independently of that process (Moscovitch, 2007, p.18).

Given these converging views it is interesting to reflect that very little attention was given to the concept of retrieval in experimental psychology until the 1960s. This is probably due to the fact that from 1930 until 1960 most researchers in this general area were studying models of learning, so the emphasis was on conditions of effective learning on the one hand, and on the causes and conditions of forgetting on the other. Retrieval processes as such were not really considered, as the learned response was assumed to be evoked by the "stimulus term" of a learned association, or by reinstatement of a task in its learned context. As the emphasis shifted gradually from verbal learning to cognitive approaches in the 1960s and 1970s, however, interest in the concepts of encoding, storage and retrieval revived, and experiments were designed to explore their properties. One major new experimental

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paradigm involved the free recall of word lists (e.g., Tulving, 1962); a technique riskily involving *no* stimulus term or other cues, thereby forcing a consideration of retrieval mechanisms.

Synergistic ecphory

My own interest in retrieval processes was spurred by hearing a talk by Endel Tulving in 1967. The occasion was a two-week conference on memory in Cambridge (UK) funded by NATO and featuring such big names as Donald Broadbent, Arthur Melton, Donald Norman, and Robert Bjork. The audience consisted largely of NATO-sponsored students from a variety of European countries. Presumably it was the fond hope of NATO administrators that the students would return home buzzing excitedly about the latest information on dichotic listening and proactive interference, thereby helping to persuade their skeptical countrymen to abandon communism and embrace Western values. Who knows? But Tulving's talk was certainly revolutionary to me, and inspired me to think much more about encoding and retrieval processes in long-term memory; my research interests until then had focused largely on issues in sensory and short-term memory. Tulving had recently carried out a large-scale experiment (N = 948!) exploring the conditions affecting retrieval cue effectiveness (Tulving and Pearlstone, 1966). They presented participants with word lists composed of category exemplars, with each category group preceded by its label (e.g., Country in Europe: Germany, Spain, Belgium, Finland). List lengths were 12, 24, or 48 words, and there were one, two, or four words in each category. Finally, after presentation, recall was either cued by the category labels or no cues were provided. Predictably, cued recall (CR) was superior to non-cued recall (NCR), but this difference interacted with list length and number of items per category. For example, the combination of list length 12 and four items per category yielded CR = 0.83, NCR = 0.78, whereas the combination of list length 48 and one item per category yielded a much larger difference between the two cuing conditions: CR = 0.74, NCR = 0.32. The authors also found that the provision of cues increased the number of different *categories* represented in recall but had no effect on the proportion of *items per category* recalled. Cuing therefore increased access to some categories that were not retrieved by NCR participants, but once the category was accessed retrieval of items was equivalent between the two groups. These results made the important points that items in memory could be *available* (i.e., present in storage) but not *accessible* (e.g., in the absence of cues) and that, with availability constant, recall was highly dependent on the provision and nature of retrieval cues. The authors' general conclusion was therefore that recall depends both on storage and retrieval factors.

Tulving went on to elaborate and refine his ideas on retrieval in his influential book *Elements of Episodic Memory* (1983). The main points are re-presented here to illustrate how they led (in part at least) to my own views, and to show where his and my views converge and where they differ. Tulving assumes that the encoded record of a previous experience is stored in the brain in the form of an engram, but he stresses that the engram is not simply a copy of the experience waiting to be found by retrieval processes, rather "engrams are dispositions, potentialities, processes held in abeyance" (Tulving, 1983, p. 169). That is, the engram can only be made manifest in interaction with a relevant cue. This is the heart of Tulving's 1983 views on retrieval; information in the engram and in the complementary retrieval cue combine in a process he refers to as "ecphory." The term ecphory was first used at the beginning of the twentieth century by the German psychologist Richard Semon, whose work is described in an excellent book by Daniel Schacter (1982). The word comes from the ancient Greek meaning roughly to "bear something out" in the sense of evoking or reviving some object until now hidden from sight. In Tulving's account, the interactive combination of the retrieval cue and the memory trace yields "ecphoric information" that underlies the conscious recollective experience of the original event. Tulving stresses that ecphory is not simply another name for retrieval; rather it is the process by which aspects of the retrieval information (both specific cues and the general context of the retrieval environment) are brought into interaction with stored information to give rise to recollective experience. Since the interaction is presumed to be dynamic and complementary, Tulving's preferred label for the process is "synergistic ecphory"—reflecting his view that words in common usage (like memory and retrieval) lose their precise meanings in scientific discourse and should therefore be replaced by more specific terms. I would have to say that the term synergistic ecphory is not on every memory researcher's lips some 40 years after its unveiling in the *Canadian Journal of Psychology* (Tulving, 1982), but in my opinion the basic notion that successful recollection reflects a dynamic interaction between stored information and retrieval information seems exactly right.

The idea that retrieval information contributes something essential to the final recollective experience stands in contrast to other theoretical views (e.g., Anderson and Bower, 1973) in which the retrieval cue simply acts as a pointer to locate and activate the stored memory trace. Tulving's view also negates the popular idea that memory is like a huge library, with memory traces stored in highly specific locations depending on their encoded characteristics. In such a library, a precise call number will act as a retrieval cue to locate the stored trace and bring it back to conscious awareness, but Tulving's point is that the retrieved memory reflects an active interaction between trace and cue; neither by itself is sufficient. Another important implication of Tulving's approach is that attempts by neurophysiologists to "find the engram" are doomed to failure, since all that could be found, presumably, is a changed tendency in some neural network to yield a specific experience when combined with the appropriate cue.

One interesting source of information that apparently speaks against this conclusion concerns reports of vivid autobiographical memories experienced by patients undergoing direct electrical stimulation of the brain. These dramatic observations were first reported by Penfield and Perot (1963) in the context of neurosurgical interventions on patients with epilepsy. Similar findings were reported more recently from a patient undergoing deep brain stimulation (Hamani et al., 2008). It seems necessary to conclude that activity in certain brain regions (possibly occipital cortex and regions with access to visual processing areas) gives rise to conscious experiences of real-world events, speculatively reflecting activity in the same regions that are active when driven by perceptual input in a waking state. Dreams are the obvious common example. Penfield (1975) certainly believed that he was tapping into a sequential record of conscious experiences laid down at the time of the original events—memory as a videotape recording—but there are reasons to question this interpretation. First, the evoked sequences reported by Penfield and Perot (1963) typically involved general scenes and people from patients' waking lives, but the confused and jumbled sequence of dreamed events often do not. Tulving (1983, p. 62) is similarly skeptical, observing that the experiences related by Penfield's patients are almost all general "semantic" memories rather than veridical memories of actual episodic events.

Two other components of Tulving's (1983) scheme are *retrieval mode* and *conversion*. In Tulving's view retrieval mode is a necessary condition for the retrieval of episodic memories. He argues that real-life stimuli or events typically trigger processes of identification and comprehension but do not evoke specific episodic memories. As everyday examples, Tulving writes that if you present a photograph of a mutual acquaintance to a colleague, or say "a long journey" to him without comment, the colleague may perhaps back away in alarm but will typically not respond with a personal memory. The cognitive system has to be "set" to interpret incoming stimuli as retrieval cues according to Tulving. I agree that semantic interpretation is the norm and that episodic retrieval typically follows a specific request for information, but my personal experience is that a highly specific event with a close associative relation to an encoded episode will bring the original event back to mind spontaneously. Suppose, for example, that the colleague has had a recent emotional experience—involvement in a car accident or reunion with a girlfriend—I suspect that a photograph of the accident or of the first moments of meeting would bring the original event back to mind without further instructions or questions. I suggest, in fact, that the degree to which environmental cues evoke episodic memories *involuntarily* (Ebbinghaus, 1885; Berntsen, 2010) depends on such things as the salience of the original event and of the retrieval cue, and—critically—on the specificity of the link between the cue and the event. These factors are seen in situations involving prospective memory, where a person must remember to perform an action at some future time. People often leave reminders for themselves under these circumstances, or some environmental object acts as a reminder, and my point is that the effectiveness of the reminder to recollect the relevant intention will depend on the salience of the reminder and on the strength and distinctiveness of the link between the reminder and the encoded intention. Prospective memory is discussed further in a later section.

There seems little doubt that individuals can be set to interpret incoming stimuli as retrieval cues and that this preparatory state (in conjunction with environmental variables) will result in more effective episodic retrieval. But is this retrieval mode a *necessary* condition for retrieval success? Studies of encoding have shown no evidence of an "encoding mode"; as argued in prior chapters, perception and comprehension are sufficient to establish an encoded record. However, instructions to learn ("intentional learning") will certainly switch in further processes of elaboration and organization, and I suggest that "retrieval mode" entails a similar switching-in of such strategic retrieval processes as generation of associations and attempts mentally to recreate the original context. So, for example, if some stimulus or event evokes a faint feeling of familiarity, or there is a mismatch between expected and actual experience, deliberate attempts to retrieve more details, or resolve the discrepancy, will likely occur. Such further retrieval processing may even be switched in automatically.

Tulving's other major component of the final Synergistic Ecphory Model (Tulving, 1983, p. 311) is the notion of conversion. Ecphoric information gives rise to recollective experience, but to translate that private mental experience into a public demonstration of remembering, the ecphoric information must be converted into observable behavior—the remembered item's name, for instance, or the choice of one alternative in a recognition task. Tulving also points out that conversion is optional; it may be sufficient just to experience the event mentally. He also points out that recall and recognition require different methods of conversion, and finally that whereas ecphory is preconscious, conversion is in a sense postconscious—it necessarily follows conscious recollections of the original event.

I can add that memory-driven performance (or the effects of previous learning) can often occur in the absence of recollective experience. As an example, priming or implicit memory is the case in which a previous occurrence facilitates performance without the person's awareness of the original event (e.g., Tulving et al., 1982; Jacoby and Dallas, 1981; Schacter, 1987; Roediger, 1990). Tulving (1983, pp. 105–112) discusses such cases and debates whether they reflect processing in episodic, semantic, or procedural memory systems. He comes down rather grudgingly on the side of procedural memory, but is clearly not entirely happy with the choices on offer. It seems to me that he could have opted for episodic memory in his synergistic ecphory scheme, since there could be a direct link between ecphoric information and conversion to action without going via conscious recollection, but he leaves the question rather open.

Cue-dependent forgetting

Another of Tulving's important contributions is the notion of cue-dependent forgetting. This idea follows immediately from the assumption that remembering reflects the complementary interaction of the present retrieval cue with the encoded trace of the original event, and also that both elements are necessary for remembering to occur. If the cue is absent or only partially appropriate the event will not be remembered; not because the memory record has been lost, however. It may still be available but inaccessible owing to the ineffective cue. Thus, Tulving distinguishes trace-dependent forgetting—when the record of the original event has been totally lost—from cue-dependent forgetting, where the trace is still present in the brain but the relevant memory is not evoked owing to the insufficiency of the particular cue used. In the latter case, the memory can still be recovered by using a more compatible cue.

This situation is nicely illustrated by an experiment exploring the differences between recall and recognition (Tulving, 1974; Tulving and Thomson, 1973). Normally recognition memory is superior to recall, as the "copy cue" provided in recognition is more specific and compatible with the encoded trace than in the general retrieval processing that presumably occurs in recall. Tulving's experiment illustrates the opposite outcome by devising a situation in which cued recall is more compatible with the encoded trace than is recognition. The experiment has four phases. In the first phase participants learned a series of words, each preceded by a weak associate, for example train-BLACK, glue-CHAIR; the participant is instructed to learn the second (target) word, and to use the first word as an aid to recall in a subsequent test. In the second phase, participants were given the apparently unrelated task of generating free associates to words that were actually strong associates of the target words. So on presentation of the word WHITE, the participant might generate "*snow, sheet, black, grey*"; the word TABLE might evoke "*chair, wood, mat, knife*." In the third phase, participants were asked to examine their generated responses and circle any words they recognized as target words from phase 1. And, finally, in the fourth phase, they were provided with the original cue words (*glue, train*) and asked to recall the associated target words. The surprising result was that the probability of recognition was only 0.24, whereas the probability of cued recall was 0.63—illustrating the "recognition failure of recallable words" (Tulving and Thomson, 1973, Experiment 1). Tulving's (1974) account of this striking finding is that the original cues are more compatible with the encoded trace than are the "copy cues" of the target words themselves. It may be objected that in the recognition phase a participant would read the words *chair* and *black*, know they felt familiar, but attribute the familiarity to the fact that they had recently generated them. This account still fits Tulving's ideas, however, since the encoded event contains not only the two words, but also an attitude towards them, evoked images, interpretations of the learning situation, and so on. This complex of feelings, images, and mental orientation is much more likely to be reinstated in cued recall than in recognition, so yet again performance is arguably a function of the overlap in mental contents between encoding and retrieval. As a final thought, Tulving (1974) suggests that cue-dependent forgetting may be the general rule rather than an occasional finding; speculatively, forgetting is essentially a cue-dependent phenomenon.

Repetition of operations

One of the hallmarks of a "cognitive" approach to the study of memory and learning when it first emerged in the 1950s and 1960s was a more active role for the organism in its interactions with the environment. Rather than the person or other animal being viewed as a passive recipient of external stimulation, organisms were now seen as acting *on* the environment to fulfill their goals (e.g., Neisser, 1967). Cognition cannot be entirely a matter of acting and responding, however, so a reasonable middle position seemed to be that mental processes reflected an *interaction* between incoming stimulation, outgoing actions, and a nervous system that has adapted to interpret the resulting sensory activity and to formulate appropriate responses. This S–O–R (stimulus–organism–response) characterization of human behavior (Woodworth, 1929) led ultimately to a focus on the "O" component and on how experience modifies the brain to enable such achievements as memory, thinking, and meaning. In turn, these brain changes may be regarded as "representations" of the outside world, running from highly specific records of individual events to abstract summaries of features common to many occurrences. As discussed previously, some researchers have thought of representations as complete copies of events and ideas, accessed by cues that simply act as pointers to locate and elicit them, whereas others (e.g., Tulving, 1983) have stressed the notion of complementarity between cues and traces.

Paul Kolers took a very different view; his basic conception was that mind should be construed as the skillful manipulation of symbols. But symbols are not simply representations by another name; he suggests rather "that distinctions between mental representation and mental process, between 'symbol' and 'skill' are of questionable worth for psychology and may indeed actually misrepresent psychological processes" (Kolers and Roediger, 1984, p. 429). In Kolers' view then, procedures are everything. He goes on to claim that "knowledge of objects is specific to the means of experiencing them" and that declarative knowledge should be thought of "in operationalizable terms of actions—the procedures that characterize a person's acquisition and use of knowledge" (Kolers and Roediger, 1984, p. 429). These ideas led Kolers to vehemently reject the notion that sensory and perceptual processes are simply the packaging to convey the essential semantic meaning of a scene or interaction, and that once meaning is extracted the packaging is discarded. He illustrated how false this notion was by demonstrating that "surface" characteristics of perceived events can be remarkably long-lasting. He was equally disparaging about such apparently structural options as memory systems. In his writing he is the master of the cuttingly derogatory use of the quotation mark, as in

> One way of interpreting [dissociations in memory research] is by attributing different aspects of performance to different memory 'systems.' Tulving . . . attributes some aspects of performance to an 'episodic' system and some to a 'semantic' system. . . (Kolers and Roediger, 1984, p. 437).

All good fun, but what is the evidence?

Kolers made extensive use of a sentence-reading paradigm in which participants read text passages printed in geometrically transformed typography—for example mirror image and inverted. In a typical experiment participants were given extensive practice at reading the transformed text and then returned to the laboratory some time later to re-read the same text and new passages in the same typography, a different but equally practiced typography, or a completely new typography. The results showed good retention of the acquired skill of reading a particular typography, and also some benefit to re-reading the same passage as opposed to a new passage; neither of these results is particularly surprising. What *was* surprising, however, was the finding of a specific advantage to the same passage re-read in the original typography—retention of highly specific pattern-analyzing operations. This specific retention was found even when participants were re-tested one year following initial training (Kolers, 1976). Previously read pages from a book were re-read slightly faster than new pages from the same book, even though participants could not tell which pages were old and which were new. Thus, it seems that recognizing text is achieved by different analytic procedures than those responsible for "remembering" the acquired skill of reading a transformed typography. These studies were reported by Kolers (1973, 1975, 1976) and discussed by Kolers (1979) and by Kolers and Roediger (1984).

I carried out some experiments in my own laboratory using this technique, and the findings largely corroborated Kolers' results. The experiments were carried out by Twila Tardif, who was a bright undergraduate at the Erindale Campus of the University of Toronto at that time; she subsequently went on to graduate studies at Yale, and is now on the faculty of the University of Michigan in Ann Arbor. In one study (Tardif and Craik, 1989) we had participants read passages in each of two different transformed typographies, A and B. They returned to the laboratory a week later and read the same (old) passages in either the identical typography (e.g., A followed by A), the other practiced typography (e.g., A followed by B), or in a completely new typography (e.g., A followed by C). In this second session the participants also read completely new passages in typographies A and B (old) and C (new). The results, in outline, were that in week 2 the passages previously read in week 1 were read more rapidly than new passages, showing that some retention of the gist of previously read material aided performance in week 2. Also, passages re-read in either A or B typographies were read faster than those presented in the new typography C, showing retention of specific reading skills. Finally, we obtained some slight evidence for the more interesting effect of specificity—AA and BB were read faster than AB and BA—the difference was about 5%, although it was not statistically significant.

My graduate student Michael Gemar and I later repeated the experiment in a simplified design; participants read passages in typographies A and B in week 1, and returned a week later to read new passages and old passages in typographies A and B. The results (reported in Craik, 1991) are shown in Table 5.1 in terms of average times to read each word.

The table shows first that passages read in week 1 and repeated in week 2 are read faster than the new passages presented for the first time in week 2. This effect could be due either (or both) to some retention of the semantic gist of old passages, or to retention of the specific skilled procedures employed in reading the old passages on the first occasion. This second possibility is answered more clearly by comparing same passage/same typography conditions with same passage/different typography conditions. The mean reading time for the "same" condition was 0.835 seconds per word, and the mean time for "switched" conditions was 0.875 seconds per word; again, about a 5% advantage for the specific combination of a given text in a given typography. In this experiment the 5% advantage was statistically significant; this is approximately the same level of benefit found by Kolers (1976) when comparing the reading speed for new pages of text with speed for pages read one year earlier.

Table 5.1. Reading times (seconds/word) on week 2 of the Craik and Gemar study (Craik, 1991, Table 13.2).

Week 1 typography	Week 2 typography	
	A	B
A	0.84	0.88
B	0.87	0.83
(not presented)	1.03	0.97

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In the present context, one crucial aspect of all these re-reading experiments is the relation between reading speed on the one hand, and recognition memory for the texts on the other. Two important findings from Kolers' experiments using transformed typographies are, first, that participants' ability to discriminate previously encountered texts from new text declined as the skill of reading the transformed typography increased: "Extended practice at reading geometrically transformed text reduced its advantage to memory" (Kolers, 1975, p. 696). The second finding is that skilled decoding of transformed texts and ability to recognize texts as old or new appear to be independent phenomena. In the experiment involving re-reading a year later, for example, old passages not recognized as old were nonetheless read faster than new passages.

The first finding makes good sense from my point of view; the unpracticed reader must rely substantially on the meaning of the passage he or she is reading to decode the unfamiliar typescript, and this involvement of semantic processing aids later memory for the passage. As reading becomes more skilled there is less need to involve meaning, and memory suffers accordingly. The independence (or partial independence) of reading speed and recognition memory shown by the second finding is an interesting observation as it strongly implies that semantic analysis is not carried by the pattern-analyzing procedures themselves, but by separate semantic-analyzing operation. Kolers often writes as though the perceptual–motor processes also carry the meaning; for example, his chapter in the Cermak and Craik volume is entitled "A pattern-analyzing basis of recognition" (Kolers, 1979). In other places he seems to concede a distinction between "perceptual" and "semantic" operations, however: "Speed of reading and judgments of familiarity, frequency, and recency may actually be based on different kinds of operations" (Kolers, 1976, p. 563). To my mind this is a more reasonable position given that the same essential meaning may be conveyed by a written passage, a spoken passage, a passage in sign language, Braille, or even by a strip cartoon. There must be some common higher-level—"something!"—that enables the same comprehension to be conveyed by very different surface means. However, Kolers does insist on the crucial *interactions* between these surface means and the qualitative nuances of final comprehension; for example, changes in the way that a message is conveyed (tone of voice, facial expression, accompanying gestures) can clearly affect the implication of the message. And, more subtly, the font and color that a text communication is written in (italics, red capitals, Gothic script) also change the meaning picked up by the reader.

One way of reconciling these apparent differences is to endorse the widely accepted view that the various sensory input modalities—visual, auditory, tactile, etc.—are processed in a hierarchical manner, with early analyses representing modality-specific sensory aspects of the input, and later higher-order analyses representing more abstract, generalized, and context-independent aspects (Botvinick, 2008; Cohen, 2000; Craik, 2007). In this scheme the analyses are in a sense continuous from specific to abstract, but the qualitative nature of what the analyses represent gradually changes (see Chapter 10 for a fuller discussion of this point). If we also think of the various modality-specific input streams progressively merging at the later, higher-order ("deeper" in LOP terms) stages of analysis we have a way of explaining how an auditorily presented word may later be recognized via a visually presented probe word. In this scheme acquired knowledge is certainly "means-dependent," as Kolers insisted, but the higher levels of analysis also make contact with higher-level analyses from other modalities—essentially because at these higher levels both streams are representing some common aspect of the outside world—objects, scenes, people, their interactions, and, ultimately, their significance. That is, the "sensory" gradually shades into the "semantic," and aspects of semantic representations are common to different sensory inputs—for example we can be shown an object visually and later pick it out while handling it blindfolded.

The idea of perceptual patterns shading gradually into semantic meaning is perhaps seen more clearly in cases involving non-verbal materials. Examples include chessboard settings which, through learning, provide the expert with deep meaning and implications for action: Professional wine tasters (or whisky tasters for that matter) obtain complex meanings about origins in time and place from a few sips; art professionals can tell genuine works from fakes on the basis of brush strokes and other aspects of composition; and musicians can readily identify composers from their specific use of melody and harmony.

This is a *processing* scheme, in that encoding operations involve early sensory-specific analyses and also such later semantic analyses as are necessary and appropriate for the task at hand. Similarly, retrieval operations are seen as recapitulating encoding operations as Kolers and others (e.g., Wheeler et al., 2000) have suggested. Following Jacoby (Jacoby, 1983; Jacoby and Dallas, 1981), performance on the retrieval task will depend on the processing requirements of the task; and the match to those requirements provided by the processing carried out during encoding. So, for example, performance on a perceptual identification task (Jacoby, 1983) and on "data-driven" implicit tasks such as word-fragment completion (e.g., Roediger et al., 1989) depends on the amount of overlap in perceptual processing between encoding and retrieval. Performance on "explicit" retrieval tasks such as free recall and recognition memory depend, however, on the depth and elaboration of initial semantic processing carried out on the material during encoding (e.g., Craik and Tulving, 1975). Thus, in all cases, the basic notions of transfer-appropriate processing (TAP) and repetition of operations apply (Bransford et al., 1979; Kolers, 1973; Morris et al., 1977; Roediger et al., 1989).

Retrieval as recapitulation of encoding

As suggested in several previous chapters, my own preferred view of retrieval is that remembering is effective to the extent that retrieval processes recapitulate the processing operations that occurred at the time of encoding. This general viewpoint was suggested to me in the Toronto environment of the 1970s by reading articles by Paul Kolers and Endel Tulving, and reinforced by conversations with Larry Jacoby. As described earlier, Tulving's view was that remembering occurred as a function of the complementary interaction of the retrieval cue with the encoded trace ("synergistic ecphory"). Another major insight was his development of the notion of encoding specificity—the idea that events are encoded subjectively in a highly specific manner, shaped by the person's interpretation of the event and finely tuned both by the prevailing external context and by the internal mental context provided by the person's mood, goals, and intentions. Crucially, a retrieval cue at some later stage will evoke recollection of the original event "if and only if" the cue was first encoded as part of the initial encoded complex (Tulving, 1983, p. 210): That is, there must be substantial overlap between the way the cue is encoded and the way the original event was laid down in the memory system. As examples, if the word jam was initially encountered in the phrase "strawberry jam," the subsequent cue "traffic" would be ineffective, whereas the cue "toast" would be more effective; if the word bridge was encoded in a transportation context, the cue "card game" would not be effective. In these examples the words jam and bridge clearly change meanings between encoding and test, but the same principles apply to more nuanced changed interpretations. So, for example, the word "water" evokes different images in the pairs "lake–water" and "whisky–water," and this difference would be reflected in the differential effectiveness of the cues "drink" and "swim," even though (let's say) these two cues are equally strong associates of "water" presented in a neutral setting. The encoding specificity principle was proposed and persuasively illustrated in an important article by Tulving and Thomson (1973).

"Transfer-appropriate processing" is another influential idea proposed in the same era. The original article by Morris et al. (1977) was essentially a critical assessment of the LOP ideas. They demonstrated that when the retrieval cues in a verbal paired-associate study were rhymes of the target word, rhyme processing at encoding was superior to semantic processing at encoding; a typical result was semantic encoding/rhyme test = 0.30, whereas rhyme encoding/rhyme test = 0.45 (Morris et al., 1977, Experiment 3). However, as pointed out in Chapter 1, whereas the rhyme–rhyme combination is, indeed, superior to semantic–rhyme, the combination of semantic encoding with a transfer-appropriate *semantic* test is strongly superior to both. In Morris et al. (1977) Experiment 1, for example, the probabilities of cued recall were rhyme–rhyme = 0.49, semantic–rhyme = 0.33 (confirming the TAP claim), but the combination semantic–semantic yielded a recall probability of 0.84, markedly superior to the 0.49 for rhyme–rhyme. The commonsense conclusion is that to understand the complete pattern of results, the type of initial encoding and the compatibility of encoding and retrieval processing must *both* be taken into consideration.

This conclusion is also illustrated by the results of a study by Fisher and Craik (1977) published at the same time as the Morris et al. (1977) article. In our article, Ronald Fisher and I reported an experiment in which single words were encoded with an accompanying context word that was either a rhyming word or a strong semantic associate. The retrieval phase involved a cued recall test in which the cues were either identical to the context word used at encoding, of a similar type to that context word, or of the alternative type—that is, a rhyming cue replaced the semantic context word used at encoding or vice versa. So if the word to be remembered was HAIL, it might be encoded with the rhyming word *pail*; at test, the cues would then be *pail* (identical), *tail* (similar), or *associated with snow* (different). Words encoded semantically were also given an identical cue, a similar semantic cue, or a different type of cue (a rhyming word). So the experiment manipulated both depth of processing (rhyme vs. semantic) and the similarity of the retrieval context to the encoding context. The results are shown in Table 5.2.

An analysis of variance on these results showed significant effects of LOP (associate > rhyme), of similarity (identical > similar > different) and also a significant interaction between the two variables. This last result means that the superiority of semantic over rhyme encoding increases with increasing compatibility between the encoding and retrieval contexts; alternatively, the compatibility effect is stronger at deep levels of encoding. The conclusion is therefore that both LOP and

Table 5.2. Proportions of words recalled as a function of encoding context and similarity between encoding context and retrieval cue (Fisher and Craik, 1977, Table 3).

Encoding/Retrieval Similarity	**Encoding context**		
	Rhyme	**Associate**	**Mean**
Identical	0.24	0.54	0.39
Similar	0.18	0.36	0.27
Different	0.16	0.22	0.19
Mean		0.19	0.37

Reproduced from Fisher, R. P., & Craik, F. I. M. (1977). Interaction between encoding and retrieval operations in cued recall. *Journal of Experimental Psychology: Human Learning and Memory*, 3(6), 701–711. https://doi.org/10.1037/0278-7393.3.6.701 with permission from APA.

TAP are valid principles of memory processing, and both are necessary for a complete understanding of encoding–retrieval interactions.

My friend and partner in crime Bob Lockhart made a proposal some years ago that (unusually for me) I find difficult to accept. While discussing the central point of why deep encoding is associated with better memory than shallow encoding he suggested that perhaps the combination of semantic encoding and semantic retrieval represents a greater degree of transfer-appropriate overlap than does the corresponding match for a shallower type of processing. He further suggested that "shallow processing may be more vulnerable to a mismatch produced by small variations in the retrieval environment. It presents, as it were, a smaller target for retrieval processing and, to pursue the metaphor, is thus vulnerable to the slightest misdirection" (Lockhart, 2002, p. 400). It is an interesting idea, but the Fisher and Craik data shown in Table 5.2 seem to suggest exactly the opposite. For rhyme encoding, as the retrieval cues become more similar to encoding (from different to similar to identical), the proportions recalled are 0.16, 0.18, and 0.24, whereas for the deeper associate encoding the corresponding figures are 0.22, 0.36, and 0.54. If you imagine two normal distributions representing sensitivity to different cues, with peak sensitivity at the middle of the distribution, then rhyme encoding would be represented by a flattish function peaking at 0.24, whereas the associate encoding would be represented by a taller, skinnier function with steeper slopes peaking at 0.54. This suggests that deeper encodings have the greatest potential to support excellent recollection but do so only if the retrieval environment provides a highly compatible cue. Moscovitch and Craik (1976) made a similar argument when discussing the "uniqueness" ("distinctiveness" is a better word) of deep encodings. I should add that Bob Lockhart has pointed out that if the Fisher and Craik study had involved a recognition condition, the conclusion might be different—that rhyme-encoded words might show a greater drop between recognition and the same-cue condition than semantically encoded words. Once again, more studies are needed!

The notion that both LOP and TAP are necessary ingredients for good memory performance led to what turned out to be a rather foolish disagreement between Endel Tulving and myself. On the basis of his encoding specificity principle Tulving argued that all we need to know to understand retrieval is the compatibility between the information in the memory trace and in the retrieval cue, resulting in effective ecphoric information. On the basis of the Fisher and Craik experiment I argued hotly that we *also* need to know something about the goodness or depth of the initial encoding. We argued pointlessly for several months until during one such debate one of Endel's bright young graduate students, Daniel Schacter by name (Whatever became of *him*, I wonder?), quietly pointed out that we were simply talking from different viewpoints—Craik from *before* encoding took place, and Tulving from *after* the event had been encoded. We were duly humbled but basically pleased, I suppose, that our theoretical offspring could coexist!

Further studies supporting the TAP framework (and therefore the broader principle of retrieval viewed as recapitulation of encoding) have appeared steadily in the 40-odd years since the effect was first documented. A comprehensive chapter by Roediger et al. (1989) provided convincing evidence that dissociations between implicit and explicit memory may be understood in terms of transfer-appropriate procedures. Explicit tests require some recollection of the initial encoding event, whereas implicit tests show the benefit of a prior experience in better test performance, without participants necessarily knowing the source of the benefit. Roediger et al. argued that explicit tests of retrieval such as free recall and recognition are heavily dependent on semantic or conceptual information, and showed that such tests benefit from semantic processing at the time of encoding. However, implicit tests such as perceptual identification, lexical decision, word-fragment, and word-stem completion depend substantially on perceptual information and thus benefit from procedures that enhance perceptual processing during encoding but are insensitive to semantic manipulations. Implicit and explicit retrieval tests are therefore described as being "data-driven" and "conceptually driven," respectively. Roediger and colleagues attribute dissociations between the two types of test first to differential sensitivity to perceptual and conceptual information, and second to the transfer of appropriate processing procedures from encoding to retrieval. However, not all instances of implicit tasks depend on perceptual processing. One nice example of semantic priming is provided by a study of spelling by Jacoby and Witherspoon (1982). In a first phase, participants were given a general knowledge quiz in which the question included the less frequent member of a homophone pair, e.g., read–reed and air–heir. So the participant might be asked to name a musical instrument that employs a reed. In a subsequent spelling test participants were asked to spell words presented to them auditorily; they showed a strong tendency to produce the low frequency member of the homophone pair. This result was found even in amnesic patients who did not remember having been asked the prior question.

A study by Franks et al. (2000) further refined the application of TAP principles to implicit memory tasks by demonstrating that same-task priming was greater than cross-task priming in a variety of implicit tasks. So, beneficial effects were clearly quite specific to specific implicit tasks; it's not the case that just any perceptual encoding will enhance later test performance. The same conclusion was expressed by Rabinowitz and Craik (1986), who explored the generation effect (see Chapter 4) in explicit cued recall. In essence, they found that word generation can be accomplished using different cues; e.g., the word MONKEY can be generated either by pairing the fragment M - - K - Y with a semantic description "a jungle animal" or with a rhyme cue "rhymes with spunky." The potential benefits of generation at encoding were revealed in a cued recall test *only* when the retrieval cue information was the same as that used during study, and (confirming the earlier results of Fisher and Craik, 1977) identical cues gave more benefit than did similar cues of the same general type (see also the study by Glisky and Rabinowitz, 1985, described in Chapter 4).

In general, it seems clear that repetition of the same processing operations at encoding and retrieval benefit performance for both implicit and explicit memory tasks. The more radical position is that repetition of the same processing operations *is* memory (Kolers, 1973; Kolers and Roediger, 1984), and this is the conclusion that I personally endorse. This interpretation of remembering has been greatly boosted by the advent and eventual dominance of neuroimaging in the field of cognitive psychology, and there is now overwhelming evidence that the processes of remembering essentially recapitulate the same processes that took place during initial encoding of the event (Danker and Anderson, 2010; Johnson and Rugg, 2007; Skinner et al., 2014; Wheeler et al., 2000).

Environmental support

Context plays a central role in human memory. At the time of encoding, various aspects of the current context—place, significance of the experienced event, the people present, mood of the perceiver, etc.—all shape and modulate perception, and therefore the major and minor characteristics of the encoded event. In light of the previous discussion of repetition of operations and the notion of retrieval as recapitulation of encoding processes, it makes sense that retrieval of a previous occurrence will be facilitated by re-presentation of the original context, and there is overwhelming evidence that this is the case. At an anecdotal level, there is the belief that "re-visiting the scene of the crime" will jog the memory of an eyewitness with respect to details of the event; there is also the irritating everyday experience of forgetting what you came upstairs for but remembering when you returned downstairs to your original location. In the laboratory such beneficial effects of contextual reinstatement are also well documented. As discussed previously, the notion of encoding specificity (Tulving, 1983) and TAP (Morris et al., 1977; Roediger et al., 1989) capture the idea that re-presenting some aspects of the original encoding situation as retrieval cues boosts recollection. The concept of state-dependent learning also illustrates the point that reinstatement of the initial learning context at the time of retrieval enhances performance.

One recurring theme in this book is the notion that the processes involved in remembering are similar to the processes involved in perceiving; both are concerned with the representation of external events (past or present) in our internal conscious awareness. Furthermore, I have previously suggested that "memory encoding" is nothing more than the processes of perceiving and comprehending, and that "memory retrieval" is nothing more than an attempt on the individual's part to reinstate the same processes (experientially and neurologically) that were active at the time of initial perception (Craik, 2002, 2007). Clearly, remembering is not *identical* to perceiving; there must be postperceptual processes involved in establishing the memory record (whatever that turns out to mean), and further processes involved in reactivating these records. But it also seems clear that these latter processes are greatly aided by re-presenting aspects of the original encoding situation. Following this idea of processing similarity we can suggest that just as the final percept reflects some interaction between the perceptual input and the person's stored knowledge as a means of interpretation, so memory retrieval reflects a similar interaction between the externally provided memory query, relevant cues, and context reinstatement, on the one hand, and the internally represented memory record, relevant knowledge, and reconstructive processes, on the other hand.

In the laboratory, conditions of low environmental support are mimicked by the free recall paradigm, in which no cues are provided. When cues *are* provided, in the shape of aspects of the original learning conditions, performance improves, and this improvement is particularly marked when learned items are re-provided in a recognition test (see the experiment on aging by Craik and Byrd, 1982, described in Chapter 3). Self-initiated retrieval processes may be less effective in older adults than in younger adults either (or both) because attentional resources decline in the course of aging (Craik and Byrd, 1982) or because executive processes are less effective in older adults (Bouazzaoui et al., 2013; Moscovitch and Winocur, 1992; Shimamura, 1995). In previous papers (Craik, 1983, 1986) I proposed an intuitively ordered set of common memory tasks that ranged from free recall and prospective memory at one end of the nominal scale to recognition memory and procedural memory at the other. The idea is that neither time-based prospective memory nor free recall provides much in the way of cues, so participants must generate and reconstruct the intention to carry out the designated task in the case of prospective memory, or reconstruct the encoded material in the case of free recall. Such reconstructive processes are presumably necessary in order to remember *any* previous event in a very different context. Cued recall provides greater support and recognition memory even more, given that the original items are re-presented along with distracter items. And, finally, procedural memory tasks—in which participants run through a sequence of previously-learned physical or cognitive activities, such as mirror drawing or reading text printed upside down—require relatively small amounts of self-initiated activity, given that the task is right there to be performed and there is no need to recollect the context in which the task was initially learned. Activities such as playing a musical instrument, riding a bicycle, or skating are other examples of procedural learning that are well supported by the external environment. These ideas are set out in Figure 5.1. The figure illustrates the propositions that the degree of environmental support is complementary to the amount of self-initiated activity required, and also that the predicted age-related decrement is reduced as environment support increases.

Although the ordering of memory tasks shown in Figure 5.1 was initially intuitive, the scheme was later given some empirical backing by the results of a

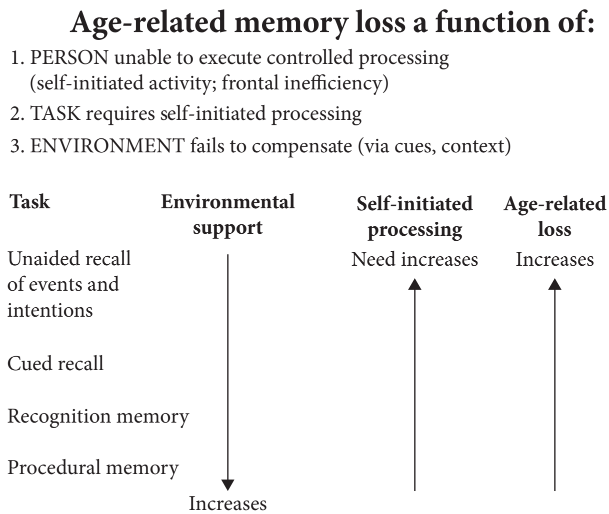

Fig. 5.1 Scheme illustrating the idea that memory performance can be understood in terms of the interaction among individual characteristics, tasks, and the environment. Tasks vary in the amount of environmental support they provide; for unaided recall of events (e.g., free recall) environmental support is lacking and therefore much self-initiated processing is required. Environmental support and self-initiated processing are therefore complementary. Older adults are presumed to be deficient in self-initiated processing (see Chapter 7), and so require good environmental support to achieve adequate levels of memory performance .

Source data from Craik F. I. M. (1983) On the transfer of information from temporary to permanent memory. *Phil. Trans. R. Soc. Lond*. B302341–359 http://doi.org/10.1098/rstb.1983.0059

meta-analysis conducted by La Voie and Light (1994). Effect size estimates for the advantage of younger over older adults was 1.05 for free recall, 0.69 for recognition, and 0.33 for priming. That is, the age-related decrement in memory was greatest for free recall, less for recognition, and least for priming.

Further evidence for the assertion that age-related differences in memory increase as the need for self-initiated activity increases is presented and discussed in the chapters on aging. I will just mention, however, that we have shown in my laboratory that age differences are greater in free recall than they are in recognition memory (Craik and McDowd, 1987; Danckert and Craik, 2013). The Craik and McDowd study also showed that recall required more attentional resources than recognition and that this difference in task demands was larger in older participants (see Figure 8.1 in Chapter 8). The difference in resource demands between recall and recognition suggests the interesting possibility that the need for attentional resources (or effortful processing, or cognitive control) increases *generally* from such tasks as procedural memory and priming (which need few resources if any), through recognition memory, to free recall and time-based prospective memory. My view is that this principle may hold as a generality but that it is probably modulated by such other factors as meaningfulness and degree of individual expertise, or familiarity with the material in question. Whereas recall is typically more effortful and resource-demanding than recognition, performance levels might be reversed if the words to be recalled were all from one semantic category, and the test list for recognition contained distracter items that were very similar to the target items. Another interesting case is Tulving's demonstration of recognition failure of recallable words (Tulving, 1974, 1983); Would item recognition be more resource-demanding than paired-associate recall in this paradigm? I suspect it would be.

In terms of endorsements of the environmental support notions, Morrow and Rogers (2008) proposed an integrative framework to apply the ideas in a human factors context. They point out the benefits of altering the task or the environment as opposed to changing the ability of the human operator by further education and training, although these two approaches are, of course, complementary and both are desirable. They also suggest that increased environmental support improves performance in two fundamental ways: By reducing demands on mental resources and also promoting more efficient use of these resources (Morrow and Rogers, 2008, p. 590). The authors comment that increased environmental support does not inevitably result in a reduction in age-related differences; in some cases more advantaged people (younger as opposed to older adults, for example) can capitalize more effectively on the improved conditions, and in yet other cases the two groups show equivalent benefits. Such different patterns and their underlying causes were illustrated and discussed by Luo, Hendricks, and Craik (2007), as well as by Morrow and Rogers (2008).

The construct of environmental support was also discussed by Lindenberger and Mayr (2014) in an article with the provocative title "Cognitive aging; is there a dark side to environmental support?" By this they don't mean to imply that such support is necessarily "a bad thing," but rather that too much reliance on external information can sometimes come at a cost to optimal cognitive control. As an example they cite an interesting experiment by Passow et al. (2012) in which younger and older adults attempted to perceive and report syllables presented auditorily in a dichotic manner (different syllables simultaneously to each ear). The relative loudness of the syllables presented to each ear was varied, and participants were instructed to attend to one ear or the other. The results showed that the younger adults could report syllables correctly from the attended ear, regardless of whether the target syllable was louder or softer than its simultaneously presented pair. In contrast, however, older adults had difficultly reporting syllables from the "softer" ear; their perception was driven largely by perceptual saliency rather than by attentional control. A further example is the greater difficulty experienced by older adults in the inhibition of irrelevant or distracting information (Gazzaley, 2013;

Hasher and Zacks, 1988). Thus, the greater reliance on external stimulation as opposed to self-initiated reconstructive or controlled processing can often aid perception and memory in older adults, but it can also have a downside.

Cognitive control is generally attributed to networks involving the superior–medial and dorsolateral regions of the prefrontal cortex (Gazzaley, 2013; Stuss and Alexander, 2007; Wang et al., 2011; Westerhausen et al., 2010), regions whose functions are known to be impaired in older adults (Raz, 2000; Braver and West, 2008). Organisms at all levels of evolutionary development require control mechanisms to ensure that their behavioral patterns fit optimally into their normal environments, and it is reasonable to suppose that for simpler organisms this control is largely provided by aspects of the external world—for example by temperature changes, light–dark cycles, magnetic fields, stable landmarks, echo location, odor, and many other "releasers" documented by Konrad Lorenz and other ethologists. But as animals climb higher on the evolutionary ladder (e.g., from insects to mammals to primates), control is progressively internalized, thereby providing greater amounts of behavioral flexibility to cope successfully with atypical circumstances. However, external sources of control still play a large part in human behavioral regulation, ideally working in harmony with internal control processes to provide a complementary balance. This balance appears to involve its greatest *internal* component in young adulthood, but it then tips back to some degree of *external* control in the course of aging. It seems clear that the age-related loss of cognitive control is a negative consequence of the aging process but can be dealt with successfully by seeking out and utilizing more environmental support as the person ages.

Environmental support and schematic support

In the 1990s my Research Associate Elizabeth Bosman and I added the construct of "schematic support" to the mix (Craik and Bosman, 1992). The idea here is that just as the external environment can help to drive the reconstructive processes of retrieval back to the configuration appropriate to remembering (or "re-perceiving") the original event, our store of learned schematic knowledge can help in the reconstruction of facts and concepts. Previously acquired knowledge at various levels of specificity may also be recruited to remember episodic events, in the sense that the sought-for information may be similar to previously experienced events. We also utilize the knowledge that "typically this happens in these types of situations." The general idea that knowledge plays a part in the reconstructive processes of memory retrieval has, of course, been emphasized by many people, including Ulrich Neisser (1967) in his seminal *Cognitive Psychology*, and John Bransford and colleagues in their ingenious work on the interpretation and recall of language (Bransford et al., 1972; Bransford and Johnson, 1972). As I will elaborate in the chapters on aging, schematic support can reduce age-related deficits in episodic memory when the material allows older people to draw on their specific stores of schematic knowledge (e.g., Castel, 2005).

However, just as environmental support has its "dark side," so too can schematic support twist recollection in favor of the typical state of affairs abstracted from many previous experiences, and away from the accurate remembering of an actual but atypical occurrence. This is the phenomenon illustrated by Sir Frederic Bartlett, the great English psychologist, in his method of serial reproduction. In these studies, a series of individuals each listens to a story and then re-tells the story to a further person. Bartlett demonstrated that the re-told stories quickly departed from the original version, became more stereotyped, more concrete, less individual, and progressively more in line with each individual's prior beliefs about the world. Bartlett was thus one of the first modern psychologists to insist on the constructive character of remembering (Bartlett, 1932). The point that knowledge and expertise can have both positive and negative effects on recall was nicely illustrated in a study led by my former student, and now a highly successful professor at UCLA, Alan Castel (Castel et al., 2007). They contrasted the recall of animal names that were also the names of American football teams (e.g., rams, colts, broncos) by participants high and low in football knowledge. The high-knowledge group not only recalled more animal names correctly, but also made more false intrusions of non-presented team names than the low-knowledge group. There was no difference in recall of names of body parts—presumably equally familiar to both groups.

The notions of schematic support and reconstructive processing are at the heart of what has been termed "accuracy-based memory research" (Koriat et al., 2000; Schacter et al., 1998). The emphasis in this approach is not so much on the *amount* remembered as on the *congruence* between the retrieved memory and the reality of what actually occurred. In this sense memory may be viewed as "perception of the past" (Koriat et al., 2000). Just as perception is concerned with the accuracy with which perceptual experience matches the external reality, so memory is also concerned with the match between experience and reality. This approach thus stresses the crucial interactions between perception and memory in a way at least similar to the ways I have talked about this topic in the present chapter and will do again in Chapter 10.

An accuracy-based approach is necessarily concerned with errors of memory and how they arise; this topic is fully discussed in the excellent review by Koriat et al. (2000). One point they make is that errors form a way to understand memory mechanisms, just as the study of perceptual illusions has proved useful in understanding the mechanisms of perception (Gregory, 1974). One example in my own work is the occurrence of acoustic and semantic errors at different time intervals in the free recall of word lists; the qualitative nature of errors points to the codes used to support recall after different delays (Craik, 1968a). In general terms I would say that the LOP framework and the accuracy-based framework are quite compatible; both have stressed the importance of qualitative differences in the representations formed at the time of encoding, and the importance of environmental and schematic support at the time of retrieval.

Internal and external contextual support

Whereas we typically think of context in memory studies as referring to the external (or environmental) context, it is also true that inherent aspects of words and objects can act to modify encoding and play a role in encoding–retrieval interactions. For example, objects may appear in different colors, words may be spoken by a male or female speaker, and visually presented words may be typed in different fonts or written by hand. Do these perceptual aspects of words and objects affect later recognition memory performance if they are changed between presentation and test? The answer appears to be "yes," although the effects are small and somewhat inconsistent. Kim Kirsner and I investigated the effect of speaker's voice on word recognition (Craik and Kirsner, 1974). As described more fully in Chapter 6, words were presented in either a male or female voice and later presented in a recognition test in either the same voice or the other voice. Our expectation at that time was that voice characteristics would be held in auditory sensory memory which was believed to last for up to 4 seconds, at most. The paradigm used was a continuous recognition test in which words were presented in a long series and repeated in either the same voice or the other voice after lags ranging from one to 32 items. The participant's task was to judge each word old (a repeated item) or new. Voice was not relevant to the recognition decision. We found a slight but consistent advantage to word recognition when the word was repeated in the same voice (see Figure 6.1). To our surprise, the effect persisted to lag 32, more than two minutes after presentation given the presentation rate of 4 seconds per word. In the published article we made the radical (for 1974) suggestion that perhaps sensory and long-term memory are not different stores or separate systems, but reflect a continuity of different types of processing. The same-voice advantage was around 4% in the Craik and Kirsner study; in further studies with Moshe Naveh-Benjamin we found a 5% effect using font and voice (Naveh-Benjamin and Craik, 1995) but no consistent effect in a later study (Naveh-Benjamin and Craik, 1996). I think the effects are real, and may depend on the degree to which the surface aspects of the stimuli affect the interpretation of the stimuli themselves. So color may be more important in later recognition of the picture of a frock than of a crayon, and voice may be more important in gender-related words, such as "truck" spoken by a male speaker or "doll" spoken by a female speaker, as opposed to such gender-neutral words as light and table.

Two bases for recognition memory

The idea that recognition memory performance reflects two semi-independent sets of underlying processes has been around since the 1970s and early 1980s (e.g., Atkinson and Juola, 1974; Jacoby and Dallas, 1981; Mandler, 1980). The two processes give rise to the mental experiences of familiarity and recollection, respectively, where "familiarity" implies that an observer feels certain that he or she has encountered an object, person, or event before, but cannot recollect details of where or when the previous event occurred. In contrast, "recollection" refers to situations in which the initial context of occurrence has been recovered and is available in consciousness for further decision-making and action. I refer to these two sets of processes as "semi-independent" rather than as two distinct memory systems (e.g., Tulving and Schacter, 1990) because I believe they can be understood in the framework of a hierarchically organized processing model. In outline, an incoming stimulation pattern is processed first by sensory analyzers and then progressively by higher-order perceptual analyzers, culminating in processing that involves abstract knowledge from many previous experiences to confer meaning and understanding to the current stimulation. The feeling of familiarity in this scheme is conveyed by repetition of processing operations (in substantial part at least) between the initial and subsequent occurrences of the event. In many laboratory demonstrations these repeated operations are sensory and perceptual in nature, but I believe that feelings of familiarity will also be evoked by repetition of higher-order semantic operations (see, e.g., Rajaram and Geraci, 2000). For recollection to occur, the incoming stimuli are processed in this same way, but, in addition, we have to assume that the processing operations evoke some structural record of the original event. So, while retaining Kolers' view as the manner in which familiarity is evoked, I have to endorse Tulving's (1983) view that information from the present retrieval cue merges with information activated from some stored record of the original occurrence to yield a complete memory that both feels familiar and also enables recollection of previous contextual details.

In this scheme, repetition of operations (perceptual and also semantic) will benefit *both* familiarity and recollection, although perhaps by different means—familiarity by the boost in fluency, and recollection by the evocation of aspects of the original event. It is well established, for example, that recollection is enhanced when remembering takes place in the same context as the original event. An additional factor is the type of information required by a particular task. For example, the ability to identify a briefly flashed word is boosted by a previous *visual* presentation of the word (Jacoby, 1983; Jacoby and Dallas, 1981) but not by a previous *auditory* presentation (Jacoby and Dallas, 1981; Clarke and Morton, 1983) or by semantic processing of the word's initial occurrence (Jacoby and Dallas, 1981). However, conscious recollection of the event *does* involve semantic information, so the LOP manipulations of Craik and Tulving (1975) consistently affected performance on tasks of explicit recall and recognition.

Thus, when visual tasks such as perceptual identification of briefly presented words, word-fragment completion, and word-stem completions are primed by previous visual presentation of target words, performance is enhanced by repetition of the same visual processing operations. This enhancement is typically seen in behavior only, however, without any awareness that the word was previously presented—either in feelings of familiarity or of recollection. The independence of priming effects and conscious recognition of previous occurrence was also illustrated in an experiment by Tulving, Schacter, and Stark (1982). They presented individual words visually for 5 seconds each and then gave participants a recognition test and a word-fragment completion test for the words after 1 hour and also (for different studied words) after 7 days. Recognition memory declined substantially from 1 hour to 7 days, but fragment completion performance did not change. Further, as the same words were tested on both tasks, it was found that fragment completion was as good for words that were judged new on the recognition test as for words correctly judged old. Thus, priming appears to be very long lasting and priming and recognition memory seem to be carried out on different aspects of the encoded information—the tests are independent (see also Kolers, 1976; Toth, 2000). Tulving (1983) concluded from these results that priming and recognition memory depend on information from different memory systems: From episodic memory in the case of recognition and from "procedural memory" in the case of priming. It seems clear that the two tasks must utilize different types of information, but in my view it is not necessary to characterize them as different systems. In terms of the hierarchical model described earlier we can say that fragment completion is performed successfully on the basis of "primed" alterations in the relatively early visual analyzing processes, whereas conscious recognition of a prior occurrence requires activation of higher-order (semantic and contextual) records.

To recapitulate my views on encoding processes, and tie them to the notions of recollection and familiarity, I am assuming that the first occurrence of an event is analyzed in ways that fit the interests, purposes, and goals of the person at that time. Depending on these and other factors such as explicit learning instructions, the person will likely attend selectively to certain aspect of the event; in turn, "attend selectively" connotes active analysis by relevant sensory, perceptual, semantic, and contextual analytic systems. I also assume that activity in these systems gives rise to two classes of effects—one experiential and the other structural. That is, first, we are consciously aware of the ongoing pattern of activity in analyzers at different stages of analysis—the processes of perceiving are biased by those features of the internal and external environments that we are attending to. The second assumption is that analytic activities change the structural neural bases of these active analyzers in subtle but long-lasting (perhaps permanent?) ways. Thus, whereas encoding is indeed represented by processing *activities* in the brain, these activities also serve to modify the very structures that support them. This means, in turn, that when an event is repeated, the same analyzers will perform their operations more easily, more skillfully in Kolers' terms, and more *fluently* in terms used by Jacoby and Dallas (1981). Remembering, in this scheme, is thus partly based on the relative fluency of processing at different levels of analysis giving rise to the experience of familiarity, and partly based on the evocation of encoded records of the original event thereby coloring the present experience with recollections of the original context.

The qualitative nature of feelings of familiarity will depend on the qualitative nature of the processing operations repeated at retrieval—visual, auditory, semantic, or contextual. Additionally, it seems necessary to suggest that there are *thresholds* for feelings of familiarity to emerge, given that such tasks as word fragment completion and perceptual identification can be boosted in performance in the absence of any experience of familiarity—although I am not aware of any tests of this notion. Once the feeling of familiarity is experienced, the subjective state *may* be attributed to a previous occurrence, or under other conditions may be attributed to an enhancement of the event's perceptual characteristics—in which case the message will be perceived as being louder or brighter than before. The notion of attribution is this context was proposed and elaborated by Jacoby, and is discussed in the next section.

Fluency and attribution

Jacoby and Dallas (1981) carried out a series of elegant experiments to illustrate differences between variables affecting visual perceptual identification on the one hand and recognition memory on the other. The studies showed clearly that whereas recognition memory was facilitated by both semantic processing and same-modality presentation of the target word's first occurrence, perceptual identification benefited only from prior presentation in the same modality as the identification test. For example, a LOP manipulation at a word's first presentation affected later recognition memory but had no effect on visual word identification. However, a same-modality manipulation (visual study–visual test as opposed to auditory study–visual test) facilitated both perceptual word identification and recognition memory.

Jacoby ascribes the beneficial effects of same-modality priming to enhanced processing fluency of the repeated perceptual operations, that is, the ease with which the perceptual processes are accomplished at the time of retrieval. For fluency to have an effect it must be *relative* fluency—that is, the word (or other object) must be processed more fluently than "it should be" given its frequency in the language or familiarity in everyday experience. Enhanced relative fluency can also benefit recognition memory by providing an additional basis for the sense that the word or object had been encountered previously. Relative fluency in recognition memory gives rise to a feeling of familiarity, although not to full-blown recollection of the earlier event. It could also be said that relative fluency provides the basis for effective remembering associated with Kolers' notion of "repetition of operations." It has been established that recognition memory is enhanced to the extent that processing of the test material is similar to the precise way that the material was processed initially. "Recognition memory performance depends on the perceptual similarity of the study and test versions of an item. A change in modality (Kirsner, 1974), orientation (Kolers, 1973), voice of speaker (Geiselman and Bjork, 1980), or the case of the letters comprising a word (Kirsner, 1973) between study and test will lower recognition memory performance (Jacoby and Dallas, 1981, p. 330)."

Jacoby and his colleagues have made a strong case for processing fluency providing the basis for the experience of familiarity and thus the judgment that the item or event has been encountered previously. Taking a cue from Tversky and Kahneman's (1973) suggestion that the subjective probability of an event depends, in part, on the ease with which the event comes to mind—the "availability heuristic"—Jacoby proposed that when an event is processed more easily than it should be on the basis of its probability of occurrence in a given context, the enhanced ease of processing may be *attributed* to memory but may also be attributed to some relevant perceptual feature. Thus, when Jacoby and Witherspoon (1982) carried out a study on visual priming of perceptual identification, participants reported that primed words seemed to "jump out" from the visual display. Similarly, in an experiment on noise judgments, Jacoby et al. (1988) found that the judged level of background noise was lower when sentences embedded in the noise were primed by a previous presentation. And Witherspoon and Allan (1985) showed that prior presentation of words not only enhanced later perceptual identification, but also lengthened judgments of the word's apparent duration of exposure in the identification test. Again, repetition of the item caused a change in processing that was misattributed to perception rather than to memory. In the same vein, Jacoby and Whitehouse (1989) found that when test words in a recognition study were preceded by a briefly flashed word, the probability of saying "old" was increased for both old and new test words when the flashed word matched the test word. So the prior presentation (the flashed word) both facilitated correct recognition and increased the probability of false alarms, with both cases presumed to occur because of increased fluency of test word processing. The effects only occurred, however, if the preceding word was *not* identified; if it was identified, participants attributed the enhanced test word fluency to the prior presentation.

I must say that I like the attribution ideas a lot! The evidence for attributions and misattributions seems strong, and the underlying notion of ambiguity between what is memory, and what is perception, fits well with my own view that both encoding and retrieval operations are essentially forms of perceptual processing. The related proposal of processing fluency is also attractive as a basis for familiarity, but I suggest that we may have to look for a different mechanism for cases of priming that are not associated with the experience of familiarity. For example, word fragment completion and word stem completion tasks are both enhanced by perceptually compatible prior presentations, but it is difficult to see that processing of a disjointed letter string (e.g., T _ _ O _ EM) or a word stem (e.g., MAR _) would give rise to fluent processing of *theorem* and *margin*. These subthreshold examples (for familiarity) seem more like cases of enhanced pattern completion; the prior presentation has primed the perceptual processing operations for the word in question, making these operations more available to be elicited (requiring less perceptual "evidence," perhaps) on the second presentation.

Involuntary retrieval and mind wandering

The great bulk of research on human memory has dealt with deliberate, intentional, and *voluntary* retrieval of memories, although Ebbinghaus (1885) proposed that *involuntary* remembering was a major category to be studied. The idea that involuntary (non-deliberate) factors play a large part during *encoding* has, of course, been studied for some time under the heading of incidental learning (e.g., Craik and Tulving, 1975, along with many others), but involuntary retrieval has been a neglected topic until recently. Tulving (1983) suggested that being in the "retrieval mode" was necessary for the successful retrieval of episodic memories, but that position has apparently been contradicted by the results of many studies since the early 2000s. One of the main contributors to this literature is Dorthe Berntsen from Aarhus University in Denmark. In a review of some earlier studies Berntsen (2010) stated that involuntary autobiographical memories (ABMs) are universal, are as frequent as voluntary ABMs, and operate on the same systems of encoding and maintenance but differ in their retrieval characteristics. She suggested that voluntary remembering requires the involvement of executive functions, whereas involuntary remembering is more automatic, is more likely to occur when the person is not fully engaged, and is triggered by associative cues provided by environmental stimuli.

Whereas voluntary memory retrieval is typically initiated "top-down" and often involves a conscious search process guided by executive functions, involuntary memory appears to be driven "bottom-up" and "favors events that provide a distinctive match to features in the current situation, which serve as cues for the memory" (Berntsen, 2010, p. 140). The point that voluntary and involuntary retrieval processes share a common neural structure is supported by a neuroimaging study carried out by Hall, Gjedde, and Kupers (2008). In this study, both voluntary and involuntary recall of emotional pictures was associated with activity in medial temporal lobes, precuneus, and posterior cingulate gyrus. However, voluntary recall also involved activity in the prefrontal cortex, presumably reflecting executive function activity, whereas involuntary recall did not. In a further study, Hall, Rubin and colleagues (2014) had participants pair sounds with scenes in a learning phase. Retrieval took place in a scanner, with half of the participants being asked to recall the associated scene when they heard the appropriate sound; the other participants were simply asked to judge the location of the sound—left or right? This second group later confirmed that they also retrieved the scenes in an involuntary fashion. In terms of brain regions, the study confirmed the earlier findings of Hall et al. (2008) that only voluntary retrieval was associated with activity in dorsal frontal regions, but otherwise voluntary and involuntary recall involved the same brain areas.

Some further points made by Berntsen (2010) include the suggestion that voluntary recall of ABMs is guided by schematized knowledge about ourselves, and so recalled events tend to be consistent with that schematized knowledge. However, "involuntary recall favors the recollection of past events with distinctive features matching the current situation and/or past events that are highly accessible due to such factors as novelty and emotion" (Berntsen, 2010, p. 138). She also comments that involuntary memories tend to be highly specific in their content, which is interesting given that the typical finding for voluntary memory is that general information about events is relatively accessible and specific details are harder to retrieve (e.g., Craik and Grady, 2002).

Mind wandering is a phenomenon closely related to involuntary memory, and is a topic that has received a lot of recent attention. As with involuntary memory, mind wandering occurs when a person is not deeply engaged in some absorbing activity. Kane et al. (2007) have shown that young adults with higher working memory capacity experience less mind wandering, consistent with the idea that people with high working memory capacity are better able to resist distraction and so experience fewer mind-wandering episodes. There is good agreement that older adults also report fewer mind-wandering experiences (Gyurkovics et al., 2018; Maillet and Schacter, 2016a, 2016b; Schlagman et al., 2009), which at first sight is curious given that working memory capacity tends to decrease at older ages (Craik and Jennings, 1992; Hasher and Zacks, 1988). It seems likely that other factors are in play here as well; for example, although older adults may be less able to concentrate and be more vulnerable to distraction, they are also less sensitive to the incidental environmental triggers that might elicit an involuntary memory in younger adults. Interestingly, Maillet and Schacter (2016b) report that although older adults reported fewer instances of mind wandering than young adults, the older people showed an increased proportion of thoughts triggered by environmental stimuli. So, plausibly, older adults are generally less sensitive to environmental triggers, but are also more stimulus-dependent and so react to triggers whose distinctive features rather precisely match a stored autobiographical record.

An alternative view was proposed by Smallwood and Schooler (2006) who suggested that mind wandering requires processing resources, and this account is certainly in line with the finding that mind wandering decreases with age, and further decreases in patients with Alzheimer disease (Gyurkovics et al., 2018). For what it's worth, I have to say that I find the "failure of executive control" view more compelling as an account of how thoughts drift off the task at hand to more appealing and typically personally relevant thoughts. Once *embarked* on these thoughts, however, it seems very likely that such thoughts are absorbing and resource-demanding, and so detract attention both from the task at hand and from other external stimuli. That is, it may be worth distinguishing between factors that initiate mind wandering and those that maintain it.

Prospective memory

Prospective memory is another topic in which involuntary remembering plays an important part. Our lives are replete with occasions in which we intend to carry out some action at a later time, ranging from the trivial, "I should check how much milk we have left" to the momentous, "I should check the dials on the nuclear reactor" or "I must remember my wife's birthday next week!" So "prospective memory" is remembering to perform some future task, and the topic has received a lot of attention in the last 30 years, both with respect to the factors that affect performance and also with respect to the *nature* of prospective memory—e.g., whether it is a different type of memory from retrospective memory. The area has been reviewed a number of times (e.g., Einstein and McDaniel, 2005; McBride and Workman, 2017; Smith, 2017), so I will not attempt to duplicate these excellent efforts, but simply comment on a number of points that seem relevant to my general world view.

Gil Einstein and Mark McDaniel are two of the major figures working in the area of prospective memory. In 1990 they attracted a lot of attention with a paper that described an ongoing task of 42 trials in which participants recalled short lists of words; participants were also asked to report each time a target word (*rake*) appeared in any of the lists. In a condition without further aids, young participants reported the target word on 47% of occasions, but the result that caught researchers' attention was that a group of older participants (aged 65–75 years) also reported the target on 47% of occurrences. This result was obtained in two experiments, so the authors concluded that prospective memory was a form of memory that did not decline with age. At that time I had been working on the notion that one major problem underlying the cognitive deficits of older adults is a failure to "self-initiate" mental processes when they are not well supported by well-learned habits or by the external environment. It seemed to me that "remembering to remember" involved a good deal of self-initiation, and therefore that prospective memory should actually decline strongly with age. This conclusion was suggested to me informally by the English psychologist John Harris after I gave a talk on self-initiation in London in 1982, and was suggested somewhat more formally by the late David Schonfield (1982) in a book of conference proceedings.

Commenting later on this rather amiable stand-off between Craik on the one hand and Einstein and McDaniel on the other, the latter authors remarked that either Craik's theory of aging is wrong or the assumption that all prospective memory tasks are high in self-initiated retrieval is wrong (Einstein and McDaniel, 1996, p. 119). To their great credit, the researchers chose to explore the latter alternative! Citing the distinction between event-based and time-based prospective memory tasks, Einstein et al. (1995) found an age-related deficit on a time-based task but no age differences on an event-based task. Time-based prospective memory tasks are those in which the participant must remember to perform some action at a designated time in the future, and event-based tasks are ones in which an event (meeting a particular person, for example, or arriving at a specified designation) acts as a cue to perform the intended action. It seems clear that time-based tasks provide less environmental support than event-based tasks so the results of Einstein et al. (1995) lined-up with Craik's (1983, 1986) suggestions. Further studies of adult age differences in prospective memory are described in the chapters on aging.

In their "multi-process framework" for understanding prospective memory, McDaniel and Einstein propose two basic processes: Strategic monitoring for the target cue, which is typically conscious and resource-demanding, and spontaneous retrieval in which environmental conditions automatically reinstate the intended actions (Einstein and McDaniel, 2005; McDaniel and Einstein, 2000). They suggest that both processes occur in prospective memory situations, at proportional rates that depend on the person, the task, and the target cue. Spontaneous retrieval may occur via "reflexive-associative theory" (Einstein and McDaniel, 2005); the suggestion here is that the individual forms an associative link between the upcoming target cue and the intended action. When the cue occurs later, the associative link automatically delivers the intended action to awareness. A similar point was made by Goschke and Kuhl (1996, p. 55), who suggested that "the intention directly sets stored action schemas or skills into a state of readiness, such that they will be automatically activated when their trigger conditions are satisfied." The authors attribute this suggestion to the contention scheduling model proposed by Norman and Shallice (1986). The general idea of automatic retrieval of an intention, or even of the intended action itself, by the appropriate cue and context is an attractive one, although it seems to me that effective success will be a matter of degree. That is, the link between the expected cue and the intention would have to be strongly made at the time of encoding, and the cue would have to be sufficiently distinctive for it to act as an effective trigger. Somewhat less "automatic" cases may well occur when the appropriate context primes the encoded intention giving rise to the feeling that "I am supposed to remember something here … " followed by a more deliberate search (Tulving's "retrieval mode"?) for the relevant action. This distinction between the "prospective" and "retrospective" components of prospective memory is well illustrated by a study (Cohen et al., 2001) described in Chapter 8. The important role of context in prospective memory is extensively discussed by Smith (2017).

What other factors affect the likelihood that the encoded intention will be carried out appropriately? In retrospective memory studies two encoding manipulations associated with better memory performance are semantic processing (e.g., Craik and Tulving, 1975) and presentation of stimuli as pictures compared to words—the so-called *picture superiority effect* (Weldon and Roediger, 1987). Both manipulations also enhance prospective memory (Einstein and McDaniel, 1996). Another effective encoding operation in studies of retrospective memory is the performance of "subject-performed tasks" or SPTs (Cohen, 1981; Engelkamp and Zimmer, 1984). In this paradigm, participants either remember a list of simple instructions (e.g., "lift the pen," "scratch your nose") or actually perform the action. Later memory performance is substantially better following SPT instructions (see also Chapter 4). Koriat, Ben-Zur, and Nussbaum (1990) showed that this effect also increased the likelihood of successfully carrying out a future action. They presented participants with a series of three or four SPT commands with instructions that retrieval would be tested either by recall or by actually performing the command. As with the SPT results, memory performance was better in the second case. A related effect was reported by Goschke and Kuhl (1996) and termed the *intention-superiority effect*. They gave participants scripts describing a set of simple actions (e.g., setting a dinner table), again with instructions that memory for words from the script would later be assessed in a recognition test. Two scripts were then presented; in one condition the participant simply observed an experimenter performing the script, and in the second condition participants were informed that they would have to perform the script later themselves. Following presentation of both scripts participants were given a word recognition test in which they were asked to recognize any word from either script; the main result was that recognition latency was shorter for words from scripts to be performed. The authors attribute this priming effect to the persisting activation of an intended activity, which may in turn boost activation levels of relevant lexical units (Goschke and Kuhl, 1996, p. 61).

An extension of these ideas was proposed by Gollwitzer and Brandstätter (1997) as the concept of *implementation intentions*. These take the form of if-then plans, for example "when situation X arises, I will perform response Y" and Gollwitzer stresses that commitment to the goal and strategic plan are important factors. Given these optimal conditions, implementation intentions are associated with a greater probability of carrying out the intended actions—in these studies often real-life social intentions concerned with maintaining health and fitness.

One particularly compelling form of prospective memory failure is when a person intends to carry out an action but forgets to perform it mere seconds later. Anecdotally, this type of prospective memory impairment appears to occur more frequently in older individuals and when the foreground task is very absorbing. My graduate student Sheila Kerr coined the nice phrase *momentary lapses of intention* (MLIs) to describe the finding (Kerr, 1991). The phenomenon was also observed by Harris and Wilkins (1982) in a study in which participants were asked to signal after a given time had elapsed while watching a film. They were allowed to check the passage of time on a clock placed behind them; a video camera recorded times when they made such checks. When participants were late in responding (more than 15 seconds after the specified time) they had actually checked the time within 30 seconds of the target time on nearly half of the occasions, and checked the clock within 10 seconds of the target time on over a quarter of the occasions. It seems that intentions can drop from awareness with frightening ease, and may not return until cued by some relevant aspect of the environment. The suggestion that MLIs are more common in older adults was later confirmed in studies carried out by Robert West (West, 1999; West and Craik, 1999), who was working with me as a postdoc at the Rotman Institute at that time.

Is prospective memory a separate "type of memory"? I am on record as answering "no" to this question (Craik and Kerr, 1996, p. 231) and I see no reason to change my opinion. Prospective memory is more effective if the intention is encoded richly, deeply, and elaborately, and the action is more likely to be carried out when the retrieval environment matches the prospective context. The most interesting aspect of prospective memory is the purely prospective component where retrieval of the intention or action itself depends either on an environmental trigger or on a self-initiated reminding process. In the first of these conditions prospective memory may be considered a specific example of involuntary remembering (Berntsen, 2010), and it is surprising that there is so little cross-talk between the two topics. One apparent difference between prospective memory and involuntary memory is that whereas involuntary remembering seems to be entirely dependent on the match between aspects of the encoded record and the current environment, there are clearly some cases of successful prospective memory that are totally dependent on self-initiated reminding. Somehow the intention seems to "pop to mind" (Kvavilashvili and Mandler, 2004) uncued but at the appropriate time. For important future intentions, semi-conscious monitoring activities may cause the intention to come to mind from time to time—"remember you must do this soon"—and such monitoring may be the reason for why prospective memory is somewhat costly in terms of attentional resources (Smith, 2017). Einstein and McDaniel (2005) comment that spontaneous retrieval can be virtually cost free, especially when the prospective intention is judged to be relatively unimportant. These authors have recently extended their multi-process view to a rather grandly entitled "Dynamic Multiprocess Framework" (Scullin et al., 2013), which suggests that individuals can engage monitoring when prospective cues are expected and disengage when they are not expected. But on the question of whether prospective memory is a separate form of memory, the growing consensus seems to be that it is not; for example, in their review of the area, McBride and Workman (2017, p. 233) conclude that "prospective memory may be better described as a collection of different memory and decision making elements, instead of a specific form of memory."

As a final thought on prospective memory—*why* are intentions so difficult to remember? One possibility is that most other memories that reach conscious awareness are triggered by a cue; either by a direct question or request (e.g., "What did you eat for breakfast yesterday?" or "Please recall the words you just studied"), by an association, either from an external event ("involuntary memory") or from an internal thought, or in the case of recognition memory by processing an external event, either with the intention of selecting a wanted item (e.g., in a police lineup) or spontaneously (involuntary memory again). Other instances include the spontaneous emergence into consciousness of some topic that is of consuming current importance—a health problem, for example, or an unfinished task. Prospective memory generally lacks these more-or-less salient cues; they are entirely lacking in the case of time-based prospective memory and event-based prospective memory cues often evoke other associations (e.g., meeting a friend or entering a particular room). In contrast, prospective memory is typically heavily reliant on self-initiation and on "remembering to remember" at a specific time and place. My argument on why older people are particularly vulnerable to prospective memory failure thus follows from the evidence that self-initiated activities become less effective with increasing age (Craik, 1983) and that this age-related inefficiency is due, in turn, to decreasing efficacy of frontal lobe functions in older age (Moscovitch and Winocur, 1992; Raz, 2000; Stuss and Craik, 2020).

Summing up

This chapter, along with the previous chapter on encoding, has covered a lot of ground, so in this section I will attempt a brief summary of my present position. First, I see encoding and retrieving as dynamic processes, as *activities* of the mind and brain, so the functions of attention and memory (as well as perceiving and thinking) are viewed as strongly related activities within the general processing framework of cognition. I have stressed the similarity of retrieving to encoding, and both sets of mental processes to perceiving. No one thinks of perception as a "thing in the head"; perceiving is clearly mediated by neural network activity in various brain regions. To repeat my rhetorical question 'Where is the percept when we are not perceiving?' The answer is "nowhere." The question does not make sense. What we have, rather, are perceptual systems that are not only primarily genetically determined, but also modified by experience (possibly more so at higher levels of the sensory–perceptual processing hierarchy), and that evoke a variety of qualitatively different perceptual experiences when activated by an interaction of bottom-up and top-down inputs and influences. Quite simply, memory encoding and retrieval processes utilize exactly the same networks that mediate perception and comprehension, albeit for somewhat different functional goals.

The notion that remembering is an activity, similar in many ways to perceiving and thinking, is, of course, highly compatible with the views of several previous authors, especially perhaps those of Bartlett (1932), Kolers (1973) and Bransford et al. (1977). A further idea, stemming primarily from the writings of Bartlett and Kolers, is that remembering does not consist of a search through a memory store for discrete encoded records of experienced events, but suggests instead that the whole cognitive system is subtly altered by the original experience, and that the system then shows an enhanced tendency to recreate the specific neural configuration associated with that original experience. The likelihood of this re-creation (repetition of operations) is greatly aided by the similarity of the past and present contexts (environmental support), and I also assume that aspects of the initial configuration that are *not* induced by the present stimulus complex are nevertheless brought back to conscious awareness by processes of pattern completion. This last point is really an appeal to associationism—the idea that aspects of an experience have occurred together many times in the past to form a higher-order organized holistic mental structure; presentation of a sufficient number of these component aspects on a subsequent occasion will then tend to involve the whole previously formed complex. For this scheme to work for episodic memory I have to assume that such higher-order organized structures can be formed on one occasion, not only through many co-occurrences. But to me the attractiveness of this suggestion is that it combines the notions of repetition of operations, environmental support, *and* some version of "synergistic ecphory"—the dynamic interaction of present stimulation (plus top-down self-initiated activities) with some changed brain state resulting from the past experience.

A further point to stress is that "the memory trace" in this scheme is not by itself a complete record of a previous experience that could reinstate that experience on being activated by some neutral burst of neural energy—like re-playing a CD or DVD recording. Rather, the remembered experience necessarily depends, in part, on contextual reinstatement or on general, "standard," predictable aspects of the original event being constructed (self-initiated activities) from our stored knowledge of similar previous experiences. Thus, as noted earlier, no amount of patient excavation by neuro-anatomists will ever unearth the engram—viewed as a self-contained record of some past experience—for the simple reason that such entities do not exist.

It also seems clear that the mechanism of repetition of operations is not sufficient by itself to account for recollection of a previous episode, although it could support feelings of familiarity, perhaps through enhanced processing fluency (Jacoby, 1983). But the general notion that effective retrieval processes essentially recapitulate encoding processes, in all qualitative aspects of the original encoded event, is now very well substantiated by a number of neuroimaging studies (e.g., Danker and Anderson, 2010; Johnson and Rugg, 2007; Skinner et al., 2014; Wheeler et al., 2000). Higher levels of recollection depend in this scheme on the depth and degree of elaboration of the initial encoding, and also on the constructive support provided at retrieval both by the retrieval context and by the adequacy of self-initiated processing operations.

It should be borne in mind that the distinction between "target item" and "context" is somewhat arbitrary; it depends on the individual's personal interests and goals (Benjamin, 2010). The crucial point is the degree to which the target and context can each serve to invoke the complete original event, and on some occasions the context can be more effective in accomplishing this than the target item itself. The classic illustration of such a case is Tulving's demonstration of recognition failure of recallable words, described earlier in this chapter.

The present chapter also dealt with involuntary memory and suggested (following Berntsen, 2010) that if a current context is sufficiently similar to the context encoded as part of a previous event the initial event will be activated spontaneously. However, just as intention to learn can augment the normal processes of ongoing perception by carrying out further processing operations, so the intention to retrieve can boost successful recollection by processing the context more fully and by performing further self-initiated processing. But if the context plus the person's current thoughts are sufficiently similar to those of an encoded event, the explicit intention to retrieve is not necessary. This account again assumes the notion of pattern completion, whereby encoded details of the original event are activated by the high level of overlap between the current and original mental configurations. The chapter closed with a brief account of findings in prospective memory. Exactly why intentions are so difficult to remember and how exactly they do "pop to mind" when they are successfully recalled, are puzzles not fully resolved by current experimentation. At the present moment, however, my belief is that the mechanisms will turn out to conform to those elucidated for other forms of human memory.

6

From Short-term Memory to Working Memory

Evolution of a Construct

There is little doubt that the construct of working memory (WM) is of central importance to current cognitive psychology. Yet there is still much active debate on how best to characterize WM, how it relates to such other constructs as attention, executive functions and long-term memory (LTM), and even on whether it is actually one construct or whether "WM" is better regarded as a descriptive label for a set of related processes. In this chapter I will present my own current view of WM, based on previous articles plus the ideas and findings of a number of other authors. I will then attempt to illustrate how my present understanding has evolved from a consideration of previously popular ideas and labels, including short-term memory (STM), short-term store (STS), primary memory (PM), secondary memory (SM), and LTM. In relating this evolutionary history I will describe some of my own experiments and how their results fitted, or differed from, the ideas of the day.

The essential phenomenon to be described and understood is that humans can hold a limited amount of information in conscious awareness at any given time. Although the amount is small it is of crucial importance as it forms the basis for decisions and conscious thought processes; it enables integration of information from different sources, facilitates comprehension and learning, and enables us to hold information in a transient, limited-capacity memory system that, in turn, guides the selection of rapid and appropriate responses. In a sense, WM is the interface between the cognitive system and the external environment, in terms of both perception and action.

Initial interest in STM (e.g., Brown, 1958; Peterson and Peterson, 1959) focused on its properties as a memory store of limited capacity whose function was essentially to serve as a temporary buffer system to hold information briefly until it was needed as a response or until the information could be dealt with by higher-level cognitive processes. As will be detailed, studies in the 1960s and 1970s thus concentrated on such structural characteristics as capacity, coding dimensions, the timing and nature of forgetting (e.g., by passive decay or active interference), and the processes enabling transfer of information to a more stable and capacious

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long-term store. Many of these aspects of STM (or STS) were incorporated in the highly influential model proposed by Atkinson and Shiffrin (1968, 1971).

In contrast to such structurally based models, so-called "state" theories of WM are more process-based, and are essentially characterized as attention (or processing resources) deployed to activate one or more existing representational systems, as well as newly formed online representations (e.g., Cowan, 1999, 2016; D'Esposito and Postle, 2015; Oberauer, 2009; Shah & Miyake, 1996; Unsworth & Engle, 2007). Attentional control can also be directed to such perceptual inputs as phonology and visuo-spatial information, to output codes such as articulation and, crucially, to a variety of computational activities carried out on the activated representations. In a review of the area, D'Esposito and Postle (2015, p. 117) wrote that state-based models "assume that the allocation of attention to internal representations—whether semantic … sensory, or motoric—underlies the retention of information in working memory," and this is the view that I personally endorse. Given this, the two broad aspects of WM to understand are attentional control and representational systems. Some years ago my colleague Morris Moscovitch coined the nice phrase "working with memory" (Moscovitch, 1992) to describe WM; from my perspective I would amend that description to "working with representations."

In my own scientific thinking, the basic notion that WM reflects the allocation of attention to a variety of different types of information stems from suggestions made by Craik and Lockhart (1972). In that article we rejected the idea of a structural STS but kept the general distinction between STM and LTM by suggesting that the phenomena of short-term retention should be understood as reflecting "continued attention to certain aspects of the stimulus" (Craik and Lockhart, 1972, p. 676). The aspects attended to would depend on the level of analysis of incoming information—e.g., sensory, phonemic, or semantic. At that time we used the term "primary memory" (PM), coined by William James (1890) and revived by Waugh and Norman (1965) to refer to information held in conscious awareness, but in our formulation PM reflected the allocation of attention rather than being a memory store. Our idea thus focused largely on PM's role in prolonging incoming information after the relevant stimulation had ended; that is, on its role in learning by means of rehearsal or by associating recent inputs to other recent inputs, to pre-existing items, or conceptual schemes. I suspect that we implicitly endorsed Atkinson and Shiffrin's (1971) notion that PM could also hold information retrieved from the person's store of long-term knowledge, and indeed could also act as an output buffer, but the Craik and Lockhart article focused on the processes involved during encoding rather than at retrieval, or during decision-making or thinking. The broader view of PM as a workspace for a variety of controlled cognitive operations was the important insight contributed by the switch from the notion of a STS to the concept of WM by Alan Baddeley and Graham Hitch (1974).

One notable difference between the Craik and Lockhart notion of PM and most other views of short-term retention in the early 1970s was that these other theoretical notions envisaged the STS as a single structure that was somehow capable of holding not only letters and digits, but also words, phrases, sounds, and images. That is, STS was a single space in one central location, and various types of information were brought there for temporary storage. In contrast, Craik and Lockhart suggested:

> The phenomenon of a limited-capacity holding mechanism in memory (Miller, 1956; Broadbent, 1958) is handled in the present framework by assuming that a flexible central processor can be deployed to one of several levels in one of several encoding dimensions, and that this central processor can only deal with a limited number of items at a given time. That is, items are kept in consciousness or in primary memory by continuing to rehearse them at a fixed level of processing. The nature of the items will depend upon the encoding dimension and the level within that dimension. At deeper levels the subject can make more use of learned cognitive structures so that the item will become more complex and semantic (Craik and Lockhart, 1972, p. 679).

We thus endorsed the notion that PM (or WM) can "hold" a broad range of types of information, from sensory to semantic—it all depends on what's being attended to. In this sense, although we did not make the point at the time, our idea departed from the generally accepted point that STM (or PM) was acoustically coded, whereas LTM (or SM) held information represented semantically (e.g., Baddeley, 1966a, 1966b). However, the great bulk of work on short-term retention from 1960 onwards has dealt with verbal information (letters, words, sentences, digits) and it seems clear that such items can be held in PM most effectively in terms of their phonological or perhaps articulatory characteristics. However, it appears that verbal items are typically retrieved from SM in terms of their semantic characteristics, so the reasonable overall conclusion was that representations in PM are "acoustic," whereas representations in SM are "semantic," despite the fact (as I would now argue) that a wide range of codes are potentially available in both systems. I will go on to describe the usefulness of the PM/SM distinction in the 1970s for understanding the phenomena of short-term retention, but for the moment let me clarify that "SM" is entirely equivalent to "LTM," while "PM" is more or less equivalent to "WM." As used by Craik and Lockhart, the term PM referred to attention paid to a variety of codes (in line with current state-based views of WM), but we used PM largely to refer to holding verbal items in the form in which they were presented, whereas the term "working memory" as proposed by Baddeley and Hitch (1974) stressed the active manipulation and transformation of the information held.

Further points about how Craik and Lockhart dealt with what is now referred to as WM include the suggestion that the attentional processor was itself neutral with regard to encoding characteristics; PM took on the characteristics of the information attended to and processed. Also, since "residence in PM" depended critically on attention, we postulated that when attention was diverted elsewhere, information (by definition) was no longer "in PM" and would be "lost at the rate appropriate to its level of processing—slower rates for deeper levels" (Craik and Lockhart, 1972, p. 676). Evidence on this point is discussed later in the chapter. Finally, it is worth emphasizing that whereas the information held in PM/WM could vary in a qualitative manner between raw sensory information to abstract semantic information (thereby allowing a continuum of types of coding, at least potentially) the PM/SM distinction itself reflected a discontinuity—what we are attending to as opposed to information we know but is not in current awareness. Fifty years later this view still seems tenable to me.

A little history

Before discussing work on contemporary views of WM, I will set the stage by presenting my understanding of how the modern construct of WM evolved from earlier work on STS and PM. The idea of a limited-capacity STS became prominent in the context of information-processing approaches to perception and action (e.g., Broadbent, 1958; Miller, 1956). In Broadbent's (1958) model, for example, the central feature was a limited-capacity channel for processing information, the p-system (see Chapter 1 for a fuller description). Broadbent suggested that when incoming information exceeded the channel's capacity, there was a temporary buffer storage system—the s-system—that held the excess information until the p-system was clear. One source of this idea was studies of dichotic listening in which participants wore headphones and listened while different sets of digits were played into each ear— e.g., 947 to the right ear and 516 simultaneously to the left ear. The task is to recall all the numbers in any order but people almost always recall one "channel" (e.g., right ear) before recalling the other, suggesting that they attended primarily to the ear first recalled. If strings of four or five digits are presented to each ear, participants are likely to recall the first ear string correctly but make errors on the second string recalled. Typically, the second string has received less attention, but the result also shows that digits are lost from the s-system even in the few seconds it takes to respond with the first string.

The notion of a STS with different characteristics from the rest of memory was given a boost by the publications of experiments explicitly on the topic by John Brown (1958) in the UK and by Margaret Jean and Lloyd Peterson (1959) in the US. Brown found that after an interval of only 5.3 seconds the recall of four consonant pairs dropped from 67% when the interval was empty (allowing the participant to rehearse the items) to 26% when the interval was filled with four further consonant pairs, which the participant read aloud but did not recall (Brown, 1958, Experiment II). Interestingly, in the Introduction to his article, Brown attributes the idea behind his experiments to Bartlett:

> Immediate memory usually operates under conditions very different from those provided in conventional memory tests. Typically, it is necessary to retain information while continuing to carry out other activities. In a lecture delivered in Cambridge in 1950, Sir Frederic Bartlett suggested that forgetting might be extremely rapid under these circumstances. This series of experiments began as an attempt to put his suggestion to an experimental test, with highly positive results (Brown, 1958, p.12).

The Petersons found that retention of three letters fell to 10% after a filled interval of only 18 seconds, and Murdock (1961) showed that retention of three words fell at the same rate—suggesting that STS encoded *items*, regardless of their information content. Further experiments by Conrad (1963) and by Sperling (1963) found that when participants made errors in recall from STS, the errors tended to sound like the correct items—e.g., F for S and P for B—suggesting that verbal items were encoded in STS in terms of their phonological characteristics. Various debates followed: For example was encoding actually phonological (input sounds) or more properly articulatory (inner speech)? Also, did the rapid forgetting occur simply because of spontaneous decay (Brown, 1958) or as a function of interference from other similar activities (Peterson and Peterson, 1959)?

But, by the early 1960s, there was general agreement that the concept of STS was a necessary one, that it could hold only 3–4 items, was coded "acoustically," and that forgetting from STS was extremely rapid. This general view was questioned, however, in a persuasive article by Melton (1963). He argued that the salient characteristics of memory proper (i.e., LTM) were, first, that information was established in the system by learning, and, second, that information was lost primarily by interference from other similar mental activities. In his article Melton demonstrated that both of these phenomena occur in supposedly STS situations. So if the characteristics of STS and LTM are essentially the same, why postulate two different systems? The counter-argument was provided by Waugh and Norman (1965). They pointed out that the term "short-term memory" had been used both to specify a distinct mechanism and, more loosely, to describe any situation in which a small amount of material was held in memory for a short period. Waugh and Norman suggested that separate mechanisms did indeed exist; they preferred the term "primary memory" (PM), originally coined by William James (1890), as a label for STS, and the corresponding term "secondary memory" (SM) for the long-term store. Crucially, they also suggested that information retrieved from SM could perfectly well contribute to short-term *retention* tasks, and that this could account for the similar short- and long-term characteristics reported by Melton (1963). To summarize: Tasks involving the short-term retention of small amounts of material may draw on both PM and SM components, whereas memory performance involving retrieval of material not currently in mind, encoded some time ago (e.g., minutes, days, or years), will draw on SM only.

Three other important points underline the PM/SM distinction. First, Baddeley (1966a, 1966b) demonstrated that whereas the predominant type of encoding for verbal material in PM is acoustic, the dominant encoding in SM is semantic—that is, information in the long-term store is primarily represented in terms of its meaning, and semantic cues are the most effective means of retrieval. Second, studies of digit span, word span, and the recency effect in free recall—all of which have a large PM component—consistently show very small effects of aging (e.g., Craik, 1968b; Craik and Jennings, 1992) and even amnesia (Baddeley and Warrington, 1970), while showing large decrements in measures of SM. The third differentiating point is that information "in PM" is also phenomenologically in mind, in conscious awareness. Clearly, we are aware of facts, events, and ideas retrieved from SM, but in that case I would say that the information has now been "transferred to PM" by virtue of its activation by attentional processes.

Why all the fuss about PM and short-term retention? So far I have discussed PM in terms of information held in mind. Practically and adaptively this is an important point given that the information in mind may be laid down in SM during learning, may represent information just retrieved from SM before being reproduced verbally, or may be information manipulated to solve a problem in WM situations (Baddeley and Hitch, 1974). Thus, an understanding of the construct is central to understanding virtually all aspects of cognitive processing. I tend to use the term PM to refer to situations in which a small amount of material is held briefly and then recalled in the same form. In contrast, WM situations are those in which the material is transformed in some way, or attention must be divided between holding the material and carrying out further perceptual or other cognitive operations. As I see it, most current views of short-term retention have moved away from a focus on stores or buffers to "state-based models" of WM. However, I also believe that the PM/SM distinction played an extremely useful role in facilitating an understanding of the phenomena of short-term retention, and paved the way to the development of the richer concept of WM. In the next section I will describe some early studies.

Early studies of short-term memory in the Craik laboratory

While I was working at the UK Medical Research Council (MRC) research unit in Liverpool in the early 1960s I had the opportunity to visit other MRC units, and one particularly relevant to my interests was the Applied Psychology Unit in Cambridge. This group was led by Donald Broadbent and was probably the best experimental psychology research unit in Europe at the time. Apart from Broadbent, it had a number of other influential staff members, including some promising young researchers—Alan Baddeley, John Morton, and Patrick Rabbitt, among others. The Cambridge Unit was heavily involved in studies of attention and STM in those years: Baddeley was conducting experiments showing that the primary type of encoding for verbal material was acoustic in STM but semantic in LTM (Baddeley, 1966a, 1966b); Conrad (1964) had discovered that verbal errors in recall from STM were acoustic in nature—e.g., responding B instead of P, or brown instead of crown; Broadbent was using the dichotic listening paradigm to elucidate further characteristics of attention and short-term storage. I returned from one trip to Cambridge proudly clutching a tape-recording of dichotic digits, recorded by Margaret Gregory, later Donald Broadbent's wife. The recording had obviously been made on a late summer afternoon, as the sounds of evening birdsong in Cambridge gardens were clearly audible!

I carried out some studies of aging and selective attention using the dichotic tapes with unremarkable results—age-related decrements were found in both the first and second half-sets recalled (Craik, 1965). One of the participants was a very frail old lady who had difficulty putting the headphones on, and I remember thinking that she would recall very few if any of the two sets of three digits presented simultaneously to the two ears. To my surprise, she responded quickly and confidently "941–683," "427–395," etc., on virtually all trials—better than younger participants, in fact! And then, to my surprised inquiry about how she managed it she replied, "Oh this task was easy dear; I used to be a telephone switchboard operator!" The message, clearly, was that the "short-term store" is not some peripheral sensory device that precedes the main cognitive system, but is amenable to complex skill learning. The same point is made by the finding that STS deals with "chunks" of semantically related material (Miller, 1956; Murdock, 1961), and the observation that whereas the limit for serial recall of unrelated words (word span) is around five or six, span for words in a sentence can be high as 20. The implication is that PM (or STS) cannot *only* reflect the acoustic/articulatory features of verbal information; semantic and syntactic factors clearly play a role when the materials allow it. In a sense then, findings from the 1960s on already required that "STM" was something more than a store to hold acoustic information, but most investigators simply focused on variants of current paradigms and so did not see the need to enlarge the concept.

Long-lasting auditory information in short-term memory

While working at Birkbeck College in London between 1965 and 1971 I was extremely fortunate to have four excellent graduate students: John Gardiner, Vernon

Gregg, Kim Kirsner, and Michael Watkins. All of them went on to make important empirical and theoretical contributions to the memory literature. In one study with Kim Kirsner we explored the possible role of voice information in word recognition (Craik and Kirsner, 1974). A long list of words was presented auditorily at a 4-second rate; the words were spoken by either one male or one female speaker, and words were repeated at lags of 1, 2, 4, 8, 16, and 32 intervening items; when a word was repeated it was presented either by the same speaker or by the other speaker. Our expectation was that same-voice repetitions might benefit word recognition, either by increasing the probability of correct recognition or by speeding decision latency, but we expected that any such benefit would be short-lived—that is, would persist for only a few intervening items. We based this expectation on the work on precategorical acoustic storage by Crowder and Morton (1969). However, to our surprise, we found an advantage of same-voice over different-voice repetitions that lasted across all 32 lags—a time slightly over 2 minutes. The effect was small—about 3% (see Figure 6.1)—but highly reliable. Also, the interaction between voice and lag was not significant, showing that the same-voice advantage showed no signs of declining over the 2-minute period. Experiment II in the series measured recognition latency, and found a same-voice advantage averaging 22 msec, which also did not decline over the range of lags tested. We attributed these effects to the

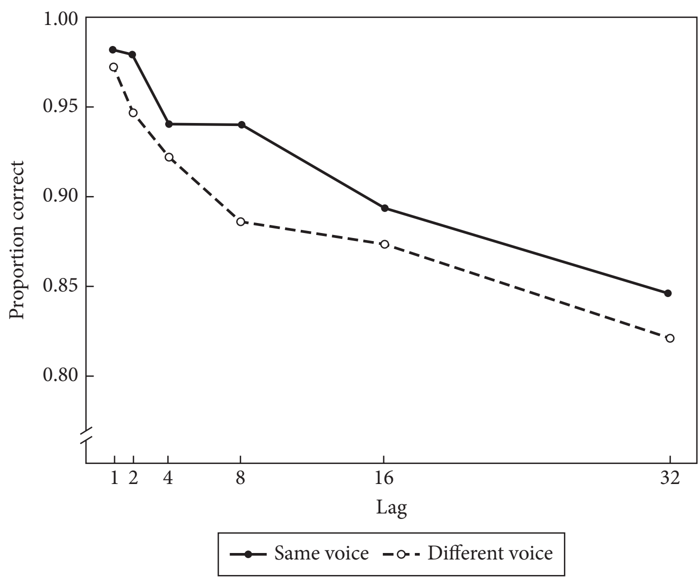

Fig. 6.1 Proportions of correct recognitions as a function of lag and of same-voice and different-voice repetitions.

Reproduced from Craik, F. I. M., & Kirsner, K. (1974). The effect of speaker's voice on word recognition. *The Quarterly Journal of Experimental Psychology*, 26(2), 274–284. https://doi.org/10.1080/14640747408400413 with permission from SAGE Publishing.

presence of long-lasting auditory information, which appeared to be specific to each encoded event (words in this case). The finding bears some resemblance to Paul Kolers' experiments on re-reading a year later, where again an advantage was found for re-reading text passages in the same geometrically transformed typescript (Kolers, 1976).

The subsequent history of the same-voice advantage has been mixed. The effect lay dormant for some years—researchers either did not believe it, or perhaps could not fit it into their current models—but it was revived in the early 1990s with the increased interest in different codes and processes. Pisoni (1993) confirmed the finding of a same-voice advantage, attributing it to a parallel memory system that encodes speaker voice with word memory; I would prefer to label it a parallel code or representational system (one of many). From this perspective the effect is simply one of many illustrating the "redintegrative" power of context reinstatement. My assumption here is that the encoded representation of any event comprises aspects of several different types of information whose power as an aid to recollection will depend on their centrality to the encoded event.

Positive findings were also reported by Palmeri, Goldinger, and Pisoni (1993) and by Campeanu, Craik, and Alain (2013), but other studies failed to replicate the effect (Church and Schacter, 1994; Naveh-Benjamin and Craik, 1995, 1996; Schacter and Church, 1992). Interestingly, Schacter and Church (1992; also Church and Schacter, 1994) *did* find a positive effect of same voice, but only on an implicit memory task (auditory word-stem completion), and this result was also obtained by Goldinger (1996), especially when the initial encoding procedure focused on voice characteristics. The finding of a same-voice advantage in implicit but not explicit verbal memory tasks echoes the results reported by Craik, Moscovitch, and McDowd (1994) who found same-modality benefits (auditory or visual presentation and retrieval) on implicit but not explicit tasks. The Kolers (1976) re-reading advantage also used an implicit task. So, in general, we may tentatively conclude that explicit memory for verbal materials (typically using recall or recognition tasks) relies primarily on semantic codes, whereas implicit tasks (e.g., word-stem completion, word-fragment completion, perceptual identification) profit mainly from "sensory" surface representations, and such representations tend to be quite long-lasting.

The primary memory/secondary memory distinction

I have always been happy with the idea that PM and SM are separate mechanisms or processes. The salient characteristics of PM for verbal materials—sharply limited capacity, acoustic encoding, rapid forgetting, insensitivity to aging and amnesia, and the experience of conscious awareness—all differentiate PM from SM in my view. The memory scene in the late 1960s and early 1970s was dominated by the Atkinson and Shiffrin model (1968, 1971). Their later (1971) article in *Scientific American* is a particularly good account of their highly influential ideas. In this model, registration of items in SM is a function of the time that any item spends in the "rehearsal buffer"—essentially how many times the item was rehearsed. This idea gives a good account of the primacy effect in the free recall paradigm; the first few words are rehearsed more often than words from the middle of the list (Rundus and Atkinson, 1970) and are also recalled with a higher probability. The Atkinson and Shiffrin model also gives a good interpretation of recency; the last few items are still in the rehearsal buffer, so are simply read out without the need for a search of SM.

Thinking about this last point it seemed to me that whereas the last few items were well recalled immediately after presentation, they would not be rehearsed as often as earlier items and therefore should not be as well registered in SM. I then carried out an experiment (Craik, 1970) in which participants were presented with and recalled ten 15-word lists in each of four sessions; the lists were presented either visually or auditorily, and participants either wrote or spoke their recall responses, one presentation/recall mode per session. After all 10 lists had been presented and recalled, participants were given a further 5 minutes to recall again as many words as they could from all 10 lists in each session ("final free recall"). According to the Atkinson and Shiffrin model the last few words should be well recalled in each immediate recall trial but poorly recalled in the final recall trial since supposedly they had not been transferred so effectively to SM. It was also assumed that many minutes after presentation all items retrieved in the final recall trial must be from SM. Figure 6.2 (data collapsed over the four sessions) shows that this is exactly the pattern of results obtained; in immediate recall the last few words are best recalled, but are recalled least well in final recall—the "negative recency effect."

We also measured the output position of words recalled in each immediate recall session; Figure 6.3 shows the probability of retrieval in final recall as a function of the word's *output* position in immediate recall. The clear result is that later output positions are associated with higher probabilities of final recall. The first few output positions are likely occupied by words from the ends of the original lists, so this analysis echoes the pattern shown in Figure 6.2. That figure also shows that the recency effect in immediate recall involves words in the last seven input positions—words arguably retrieved with some probability from PM. The low probability of final recall shown by items in output position 1–3 in Figure 6.3 thus probably reflects items recalled initially from PM. As output proceeds, however, progressively more items would be retrieved from SM, until after the seventh output position all items would have been retrieved from SM. We also suggested that the increasing probabilities of final recall might be attributable to difficult initial retrieval; that is, items retrieved later in immediate recall were retrieved with more effort, and effortful initial retrieval is somehow more beneficial for subsequent retrieval. Another possibility is that the first recall acts as a second presentation and that longer lags between these

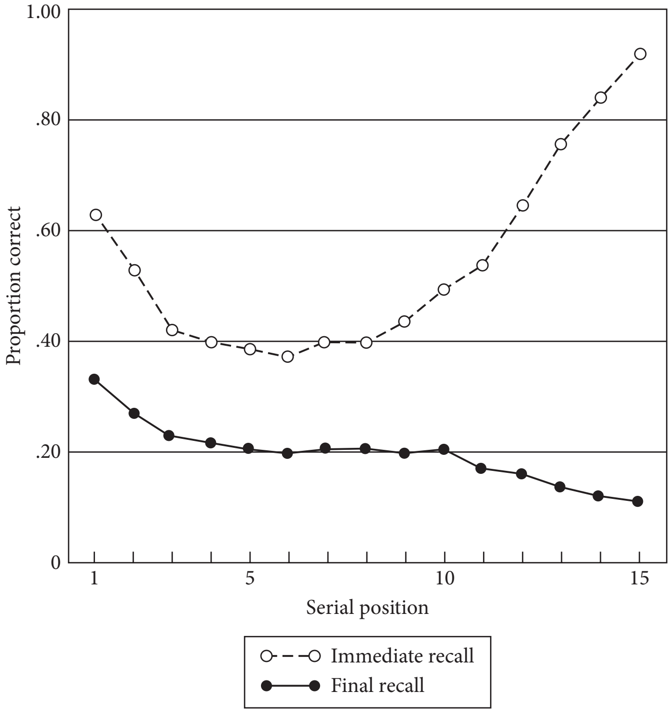

Fig. 6.2 Proportions of words recalled in immediate and final recall.
Reproduced from Craik, F. I. M. (1970). The fate of primary memory items in free recall. *Journal of Verbal Learning & Verbal Behavior*, 9(2), 143–148. https://doi.org/10.1016/S0022-5371(70)80042-1 with permission from Elsevier.

two "presentations" is associated with a higher probability of later recall—the so-called "spacing effect" (Melton, 1970). The first of these latter two suggestions must be considered in light of the later finding by Gardiner, Craik, and Bleasdale (1973) that late (possibly effortful) retrieval is beneficial to further retrieval only if the first retrieval involved some processing of the event's semantic features. It is *possible* that searching for further words to recall later in retrieval involves greater degrees of relevant semantic processing, although it is not at all clear why this should be so. Perhaps the spacing account is more likely, although of course there is the still unresolved question of why exactly spacing is so beneficial to learning.

Interestingly, the spacing suggestion was taken up again—48 years later!—in an article by Kuhn, Lohnas, and Kahana (2018). They essentially replicated the Craik (1970) study, and also explicitly measured the number of items (further presentations or recalls) between a word's presentation and its initial recall. Greater degrees of spacing in this sense resulted in a monotonic function relating spacing to the probability of final free recall; as the number of items intervening between a word's presentation and immediate recall increased, its probability of final recall

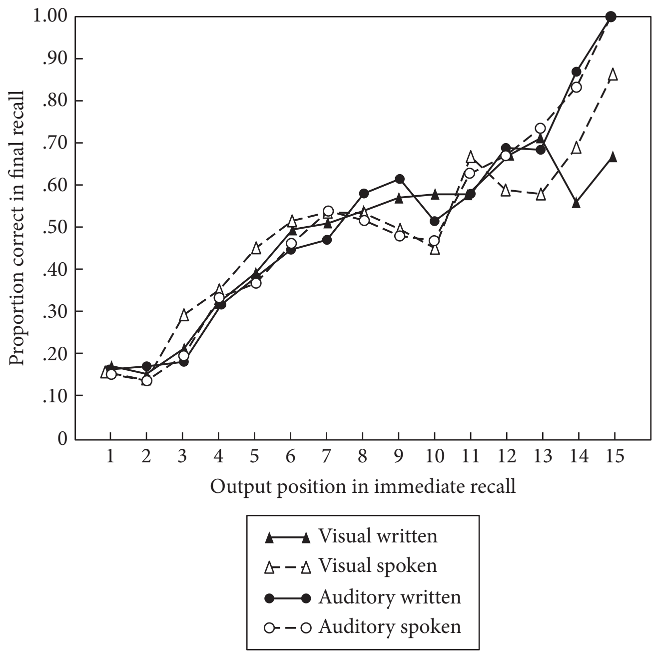

Fig. 6.3 Final recall as a function of output position in immediate recall .
Reproduced from Craik, F. I. M. (1970). The fate of primary memory items in free recall. *Journal of Verbal Learning & Verbal Behavior*, 9(2), 143–148. https://doi.org/10.1016/S0022-5371(70)80042-1 with permission from Elsevier.

also increased. Kuhn and colleagues computed the correlation between spacing and recall probability separately for every participant and found a highly reliable effect (mean correlation was +0.45) across the group. This way of assessing the effect nicely bypasses the worry that higher probabilities of final recall are simply contributed by more able participants. Kuhn and colleagues thus replicated and extended the findings of both negative recency and the spacing effect in the final free recall paradigm, but argue in favor of Kahana's (2012) one-factor model of learning and memory, as opposed to the "dual-store" model of PM and SM, which I prefer. I recommend the Kuhn et al. (2018) article to readers interested in assessing the further evidence and ingenious arguments they present. In conclusion, I remain a believer in two memory systems in this context but acknowledge that persuasive arguments for one-factor models have been advanced by several eminent theorists, including Murdock (1974) and Kahana (2012).

Other studies from my laboratory around this time included a demonstration that when participants made errors in the free-recall paradigm, errors early in output *sounded* like the correct word, whereas later errors tended to be *semantic* confusions or intrusions from a previous list (Craik, 1968a). This finding clearly supports the notion that recency items (typically recalled early in output) are encoded "acoustically" and are retrieved from PM, whereas later errors are retrieved from SM (Baddeley, 1966a, 1966b; Conrad, 1963). The Craik (1970) article discussed earlier gives good support to the Atkinson and Shiffrin model, but a later study (Craik and Watkins, 1973) gave the model more problems. Mike Watkins and I showed in two experiments that prolonged rehearsal carried out simply for the purpose of holding items in mind for a later recall opportunity had no effect on later retrieval from SM. Better learning in LTM/SM thus requires rehearsal that is deeper and more elaborate semantically to be effective (see also Jacoby and Bartz, 1972; Woodward et al., 1973). Rehearsal *time* by itself does not guarantee good registration in SM, and this finding speaks against both the "total time hypothesis" (Cooper and Pantle, 1967) and the original version of the Atkinson and Shiffrin model; both time in the buffer *and* the qualitative nature of processing must be considered.

One tricky question concerns just how much information is actually "in PM" at a given time; or what is the span of conscious awareness? Some estimates have suggested between two and four words (e.g., Craik, 1968b) and this number accords well with the estimate of "focal attention" in Cowan's (2001) model of WM. However, various manipulations of meaningfulness can clearly increase the amount of information recalled immediately; for example, predictable digit patterns such as 1, 3, 5, 7 and clusters of related words such as dog, horse, pig (Levy and Craik, 1975). If the words form a sentence, recall can be as high as 20 words. I think we have to account for such findings by saying that PM involves attention to one or two anchor words to start recall plus some representation of the gist of the remainder. This gist or set of cues then provides good support to retrieve the further information from recently encoded SM. That is, as reported later in this chapter, even immediate-span situations can have an SM component, as well as a PM component. The capacity of PM has been measured in various ways described by Waugh and Norman (1965) and by Craik (1968b). One of the most straightforward methods was suggested by Tulving and Colotla (1970), who suggested that a recalled word could be classified as retrieved from PM provided that no more than seven words (either later stimuli or responses) intervened between its presentation and its recall. Further recalled words were regarded as retrieved from SM.

A further case of SM recall in short-term situations is provided by the phenomenon of release from proactive interference (PI). In this paradigm (Wickens, 1970), participants are given a small amount of material to remember—typically three consonants or three words—they then perform some rehearsal-preventing task (e.g., counting backwards in threes from a large number for 30 seconds), and finally attempt to recall the original word or consonant triad. Recall levels are typically high on the first trial but decline substantially on the second, third, and fourth trials—all carried out with different materials drawn from the same class or semantic category. On the fifth trial, some participants are given another triad from the same class, whereas other participants are given materials from a different class, for example digits instead of consonants, or animal names instead of tree names. The consequence of this switch in materials is to raise recall levels markedly relative to the non-switch group, whose recall levels remain low. Wickens' interpretation was that the decline in recall levels from first to fourth trial reflects a build up of PI, and that the relative improvement on the fifth trial reflects "release from PI."

To my mind the build-up of PI shown in these experiments represents a progressive decrease in *retrieval* discriminability from SM as trials proceed (as opposed to say a decrease in encoded strength), with a corresponding increase in discriminability when the words to be remembered are drawn from a different category on trial five. I suggest that the effect reflects the SM portion of recall given, first, that retrieval is after 30 seconds of rehearsal-preventing activity, and, second, that the relevant encoding dimension appears to be "meaning" in a rather broad sense (Wickens, 1973); semantic encoding is the hallmark of SM encoding. So I endorse the view that retrieval from SM is substantially a matter of the distinctiveness of the target material relative to its temporal and semantic neighbors (Brown et al., 2007), as well as the congruity and distinctiveness of the retrieval-cue/target pairing (Moscovitch and Craik, 1976). To sum up, although the release from PI paradigm clearly takes place in "short-term memory" situations, it appears to reflect the SM aspect of STM.

As a further piece of evidence in favor of this last statement, I will mention a study by Craik and Birtwistle (1971) in which participants were given eight successive lists of 15 unrelated nouns to recall under free-recall conditions. The participants were instructed to recall the last few words first of all to ensure that the typical recency effect was reflected in PM recall. Figure 6.4 (left panel) shows recall from the eight successive lists (trials) decomposed into PM and SM components using the method suggested by Tulving and Colotla (1970). It is clear that PM recall remains essentially constant over the eight trials, whereas words recalled from SM decline, even bearing in mind that the materials were unrelated nouns in all lists. The size of the PM component varies between 3 and 3.5 words, in good agreement with measures of PM using other methods (Cowan, 2001; Craik, 1968b). Additionally, the insensitivity of PM recall to the build-up of PI (as demonstrated by the decline in SM recall) is in line with the insensitivity of PM to other variables that *do* affect SM recall, for example word frequency (Raymond, 1969), divided attention (Anderson and Craik, 1974), aging (reviewed by Craik and Jennings, 1992), and amnesia (Baddeley and Warrington, 1970).

A second experiment (Craik and Birtwistle, 1971, Experiment 2) used the same paradigm to investigate release from PI. In this study half of the participants were presented with five successive 15-word lists for free recall (again with the instruction to recall the last words in each list first of all). All 75 words were drawn from the same semantic category (e.g., animal names, fruit and vegetables, household objects) and, again, recall was separated into PM and SM components. The other half

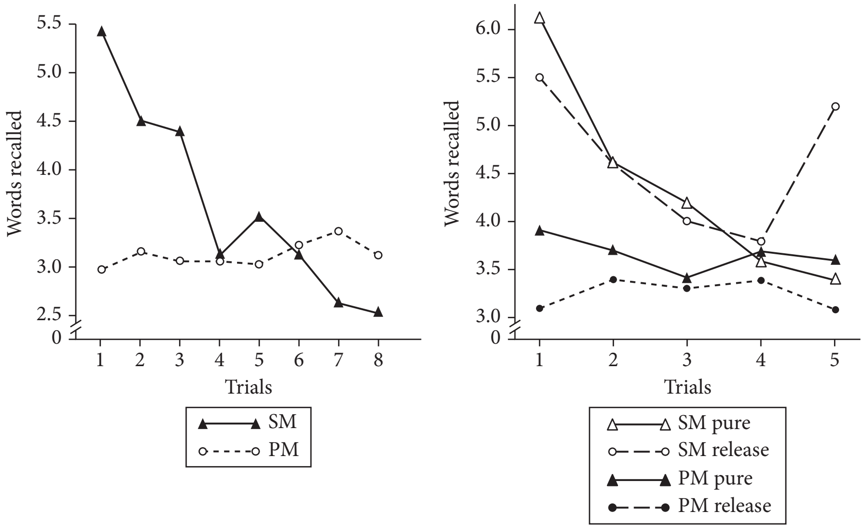

Fig. 6.4 Words recalled from primary memory (PM) and secondary memory (SM) as a function of trials. Left-hand panel: recall from eight successive lists (Craik and Birtwistle, 1971, Experiment 1). Right-hand panel: recall from five successive lists that were "pure" or "release" (Craik and Birtwistle, 1971, Experiment 2).

Reproduced from Craik, F. I. M., & Birtwistle, J. (1971). Proactive inhibition in free recall. *Journal of Experimental Psychology*, 91(1), 120–123. https://doi.org/10.1037/h0031835 with permission from APA.

of the participants were also presented with five successive word lists for free recall, but in this case the first four lists were all drawn from one semantic category, but the fifth list was drawn from a different category. Figure 6.4 (right panel) shows that PM recall remains relatively constant (3–4 words) across all five trials from both groups, whereas SM recall declines for both groups for the first four trials, continues to decline on trial five for the first (PI) group but shows a marked recovery on trial five for the second (release) group. Again, the conclusion is that both the build up and release from PI are SM effects. Retrieval from SM depends on the local distinctiveness of targets (especially, perhaps, semantic distinctiveness; Wickens, 1973), whereas retrieval from PM reflects the recall of words that are largely "still in mind" and reflects the limited capacity and acoustic encoding of verbal items held in PM. To give some local context, I can add that this second experiment was suggested by my London colleague and friend Elizabeth Warrington—the eminent neuropsychologist. Tim Shallice and I organized a regular memory seminar jointly between University College London and Birkbeck, whose guiding principle was that we all retired to a nearby pub (the Marlborough Arms … still there 50 years later!) after each session to continue our high-level discussions. After describing Experiment I to Elizabeth, she suggested Experiment II, but later graciously—yet adamantly—turned down the invitation to be an author on the article ("I'm only an author on studies that I initiate myself!"). Happy days!

A further study exploring the release from PI effect was reported by Gardiner, Craik, and Birtwistle (1972), and this study yielded an unexpected twist in the tale! In the experiment three words were presented on each trial for recall after 15 seconds of demanding intervening activity. Four such presentation and recall trials were given, and all 12 words were drawn from the same general category, either flowers or games. Judges had previously categorized the flower names into the subcategories wild flowers and garden flowers, and also the games into indoor and outdoor games. In all conditions words in the first three trials were all drawn from one subcategory (e.g., garden flowers) and the fourth trial words were drawn from the complementary subcategory (wild flowers). There were three conditions: In all conditions participants were given the general category name as a cue (e.g., "flowers") prior to the first set of three words; no specific cues were given on trials two and three; after 15 seconds of filled activity they were given the neutral cue "words" as a signal to recall. On the fourth trial the control group continued to have no cue at presentation; for a second group "cue at presentation" (CP) was given the subcategory label "wild flowers" before the three words were presented (that is, at encoding); and in a third group "cue at retrieval" (CR) was given no cue at presentation but was cued "wild flowers" before commencing retrieval. The results were that performance declined from trials one to three in all groups, thereby demonstrating the buildup of PI. The control group showed no release on trial four (despite the subtle shift in subcategories), but both the CP and CR groups *did* show substantial and comparable release effects—essentially doubling the recall level of controls.

The CP result is unsurprising; participants clearly encoded the new subcategory items in a distinctive manner. The CR result *is* surprising, however; presumably, participants encoded the trial four words in the same way as control participants, yet they were able to use the new subcategory retrieval cue to better distinguish current from previous items. In summary, although this is clearly a "short-term memory" experiment in that a small amount of material was recalled after a brief time interval, I would say that retrieval was from the SM component of STM given that semantic distinctiveness affected recall performance. The experiment also illustrates the point that "release from PI" can be achieved either by cuing the participant to encode the items in a way that distinguishes them from previous items, or by providing a cue at retrieval that acts as a selection device to enable a comparable degree of distinctiveness and recall success. It may be added that this finding appears to draw on similar processes to those described by Jacoby, Shimizu, Daniels, and Rhodes (2005a), and by Halamish, Goldsmith, and Jacoby (2012) under the heading "source-constrained retrieval"—the idea that knowledge of the source of sought-for items constrains the nature of information coming to mind—a type of "guided ecphory" in Tulving's terms. In Jacoby's theoretical framework the concept of source-constrained retrieval is contrasted with post-retrieval monitoring in which retrieved information is edited for relevance before being selected for output. It seems possible that both sets of processes may have operated in the study by Gardiner and colleagues. That is, source-constrained retrieval would sensitize the participant to select relevant fourth-trial words, and post-retrieval monitoring would serve to reject non-relevant words that might come to mind from previous trials.

To summarize these ideas and findings, our thinking at that time was that short-term retention was mediated by a mixture of PM and SM processes, where PM referred to attention paid to a strictly limited set of features—typically phonological or articulatory features in the case of verbal materials—and SM referred to the retrieval of recently encoded information that had been dropped from conscious awareness but was still primed and therefore highly accessible. Thus, information "in PM" is in conscious awareness, and this information can be augmented by further information (typically semantic in character) imported from SM. This characterization of PM is thus similar to modern ideas of WM in that both involve attention to representations, but PM is more limited in that it is essentially restricted to holding items in a rather static fashion, whereas the essence of WM is that the information is manipulated, transformed, and integrated with other information. PM and WM are therefore not "separate systems" in any sense—rather, they exist on a purely descriptive static–dynamic dimension of activity.

The roles of primary memory and secondary memory in short-term retention

In this section I will expand on the descriptions of PM and SM and describe some experiments that clarified their role in the short-term retention of verbal information. As in modern state-based theories of WM, my view of PM in the 1970s also entailed attention paid to representations but, given that we were dealing almost exclusively with verbal information, these representations were almost always phonological or articulatory in nature. When short-term retention involved semantic information, the thinking was that this information was retrieved from the more permanent LTM store, and was thus "retrieved from SM" to take part in the conscious reconstruction of the sought-for memory. As an example, when participants attempt the free recall of a long list of words, they typically first unload the last 2–3 words in the list that are still "in mind" (that is, still in PM, and thus represented by their "acoustic" characteristics) and then retrieve earlier words in the list from recently activated representations in LTM by means of their semantic characteristics (that is, "retrieved from SM").

Other arguments for the PM/SM distinction concern their different characteristics in a variety of situations. One example may be seen in Figure 6.4, where it is clear that PI and release from PI have strong effects on the SM component but no systematic effects on PM. Similarly, adult aging negatively affects SM but not PM (Craik, 1968b; Floden et al., 2000) and the same result has been reported for amnesic patients (Baddeley and Warrington, 1970). Other variables that affect SM but not PM in the free recall of word lists include list length, rate of presentation, word frequency, and the abstract versus concrete nature of words (see Craik, 1971). These findings all make sense when we consider PM to reflect the conscious maintenance of recently presented words in terms of their acoustic (or phonemic) qualities and limited by attention span. In contrast, SM information is retrieved from outside conscious awareness and generally reflects the semantic characteristics of the information retrieved. The SM component is also sensitive to variables affecting the strength, integrity, and accessibility of the underlying representations—e.g., recency of presentation and qualitative type of encoding (levels of processing variables, for example), as well as repetition effects, degree of learning, and the participant's familiarity with the material. Overall recall performance for just-presented material thus reflects a PM component (typically the most recently presented items, although participants may also choose to maintain early list items or those of particular importance) plus an SM component reflecting items presented early in the list and thus dropped from awareness during the presentation of later items.

As an example of a case in which individuals maintained important items in PM, we have used a paradigm devised by Michael Watkins and Lance Bloom in which words in a free-recall list are given arbitrary "values" (e.g., TABLE = 3; SPIDER = 20; MARKET = 14) and the task is not only to recall as many words as possible, but also to maximize the value of recalled words, so that recall of SPIDER would get 20 points and recall of TABLE only 3 points. Since the differently valued words occurred in a random order, it is beneficial for participants to maintain high-value words in mind as they are presented and then recall them first; both younger and older adults were able to do this effectively (Castel et al., 2002). In fact, recall of the three highest-value words was equivalent in younger and older adults (again showing that aging does not affect PM maintenance and recall), although younger participants outperformed their older counterparts in recalling words of lesser value (showing an age-related decrement in SM recall). Experiments in this series are described more fully in Chapter 7.

After publication of the Craik and Lockhart article in 1972 my laboratory pursued various issues related to the nature of STM, especially the idea that the short-term retention of verbal material depended on both PM (phonemic codes) and SM (semantic codes). These notions were explored in the free-recall paradigm (e.g., Levy and Craik, 1975), in the release from PI paradigm described earlier (Craik and Birtwistle, 1971; Gardiner et al., 1972), and following the suggestion that memory span for words draws on both PM and SM (Craik, 1971; Watkins, 1977). After leaving London in the early 1970s, my former student Michael Watkins and his wife Olga Watkins worked for some years with Endel Tulving at Yale. One experiment carried out there was a free-recall study using word lists of different unpredictable lengths (Watkins and Watkins, 1974a). The results showed that when participants were not informed about the list length, the negative recency effect in final free recall was abolished. The authors reasoned that if participants did *not* know when the list might end, they processed each incoming word semantically, including the last words in each list, and this deeper processing was subsequently seen as good retention of the final list words in delayed recall. Thus, it seems that when participants *do* know that they are processing the final 2–4 words in a list, they rely on the readily available phonemic processing and neglect to carry out the more demanding elaborative processing. This semantic processing is undertaken, however, when information about list length is not available.

As a sidebar, it is interesting to note that even sophisticated university students do not possess a good knowledge of how different types of processing will affect later memory performance. In several studies over the years I have noticed that when an intentional learning condition is contrasted to a condition in which participants are given an incidental semantic orienting task (for example, classifying nouns as living or non-living), the latter task very often results in better memory performance, even though the memory test was unexpected. In the same vein, Ray Shaw and I ran a study in which participants were provided with levels-of-processing (LOP) descriptors (e.g., initial letter, a rhyming word, a relevant category) for words they were learning for a later memory test. They were informed that the descriptors would be presented again as cues at the time of retrieval, and were asked to predict how well they would recall each word, given the cue. Young adult participants were *somewhat* sensitive to the LOP manipulation, but greatly underestimated its effect; mean predictions ranged from 0.57 to 0.66 for letter to category cues, whereas actual performance levels ran from 0.41 to 0.82 (Shaw and Craik, 1989, Figure 1). However, participants *were* quite sensitive to characteristics of words such as frequency, concreteness, and imageability that are known to affect recall. So, in general, people are sensitive to stable characteristics of words (and presumably other events) that affect memorability but are surprisingly insensitive to mental processing differences that also have a substantial effect on later memory performance.

From primary memory to working memory

After Baddeley and Hitch's seminal article appeared in 1974, theoretical interest gradually shifted from PM to WM. But are these necessarily different entities? Both appear to involve the continued deployment of attention or processing capacity to information held temporarily, with the difference being that material in PM is typically maintained in its initial format whereas information in WM is manipulated and transformed—is being "worked on." It is therefore possible to argue that (descriptively at least) PM and WM lie on a continuum of change to the information held in mind, with PM involving maintenance of items as presented, whereas the essence of WM is that the material is being transformed and worked on, or that the information held is being used to carry out further cognitive work. To quote Craik and Rabinowitz:

> " whereas it may be useful to talk about primary memory and working memory as different types of memory, it is probably a mistake to regard them as different structures or even as *discrete* categories. To the extent that a short-term memory task requires active transformation, manipulation, and difficult decisions about the material, we regard this task as one involving working memory. That is, primary memory and working memory may be regarded as lying on a complex continuum as opposed to being truly dichotomous types of memory (1984, p. 481)."

I am also reminded by footnote 2 in the chapter by Craik and Rabinowitz that "this point was made to us by Stephen Monsell" (who, by the way, has an excellent review chapter on WM in the same volume, *Attention and Performance X*; Monsell, 1984).

While I believe that it is useful to characterize PM as continued attention to 1–4 items and WM as further cognitive operations performed consciously on such items, attempts to integrate the two constructs within one explanatory scheme may not be fruitful. The constructs may be better understood as each belonging to its own explanatory account. In that case, how do the ideas of PM and SM map on to current theories of WM? When considering verbal material, PM for verbal information appears to be essentially equivalent to the articulatory loop in the multicomponent model of Baddeley and Hitch (1974), and PM for visuo-spatial information to be equivalent to the visuo-spatial sketchpad in that model, or to the "visual cache" in Logie's (2003) model. However, rather than postulate a series of temporary stores (or "buffers") to hold qualitatively different types of information, I prefer to endorse the notion that this aspect of WM involves attention paid to a variety of perceptual, conceptual, and premotor representations in very much the same sense as was proposed by Craik and Lockhart (1972). As I suggested previously in this chapter, attention is itself neutral, and the attended information or mental activity provides the content of the mental experience. This idea that the "PM aspect" of WM is equivalent to attention paid to a variety of representations is thus very much in line with the cognitive models of Cowan (1999, 2001) and Oberauer (e.g., Oberauer and Hein, 2012) and the cognitive neuroscience theories of D'Esposito and Postle (2015).

What about the role of SM in WM? The term "SM" has typically been used to refer to *retrieval* of information from outside current conscious awareness, and we can perhaps distinguish retrieval of a recent episode from retrieval of stored knowledge. That is, there are obvious differences between retrieval of the word

TABLE from the middle of a recently presented word list and retrieval of the same word in response to a request to "write down the names of five pieces of furniture." Baddeley (2000, 2012) has proposed that the first situation involves retrieval from the "episodic buffer," whereas presumably the second involves retrieval from a more permanent LTM. I have argued elsewhere for a continuum of contextual specificity between these extreme forms of episodic and semantic memory (Craik, 2007; see also Chapter 3 in the present volume), but, in general, we can perhaps say that SM involves the retrieval of information (typically in terms of its conceptual characteristics) from outside conscious awareness to form part of conscious awareness, and in that sense would now be "in WM."

The PM/SM distinction has been useful in understanding the effects of different materials, experimental conditions, and individual differences on free recall performance. It is also useful when interpreting apparently simple paradigms such as memory span. In this task the participant is presented with a short string of digits, letters, or words, and is asked to recall the items in the same order as they were given. This seems to be a classic PM task in that the items are perceived, attended to, and reproduced in the same form. But there are some puzzling findings that complicate the story; digit span in college students (6–9 digits) is longer than the span for unrelated words (typically 4–6 words depending on word length), yet when the words form a meaningful sentence, the same participants may recall 20 words. A PM/SM account would say that the PM component (phonology or articulation, for example) is augmented by the SM component that is sensitive to meaning and grammar. That is, memory span involves an SM component whose importance increases as the material involves predictability and meaning. This account makes sense of the observation (Craik, 1970) that when measures of word span and free recall performance were made on the same participants, individual differences in word span correlated more highly with the SM component of free recall ($r = 0.72$) than with the PM component ($r = 0.49$). Thus, even word span involves the SM retrieval of words that fall outside the focal attention capacity of PM. A state-based account of these findings would presumably argue that all the processing occurs within WM but that participants can allocate attention flexibly to both phonemic and semantic aspects of the material.

The essence of WM functioning is not storage, however, but the active manipulation of the material held, and various aspects of cognitive control that involve brief maintenance of computations and plans of action. In this vein the plan for a potential response can be maintained in a state of readiness, waiting for the appropriate conditions for response execution. Intentions and plans for future actions constitute more "cognitive" examples of such response readiness. States of monitoring and vigilance might also be included provided that the intention to act when the expected event occurs is held actively in mind. Todd Braver and his colleagues (e.g., Braver et al., 2001) have proposed the similar notion that one function of

WM is to maintain a representation of the appropriate context for intended actions as a mode of cognitive control.

Characteristics of working memory

As noted at the beginning of this chapter, there is little doubt that WM is *the* central construct in current cognitive psychology. A recent Google search for "working memory" elicited the astonishing number of 835 million hits, and the more restricted query of "working memory psychology" still yielded "about 129 million results in 0.66 seconds"—the impressive legacy of Baddeley and Hitch (1974)! In this section I will present my own current view of WM. First, I endorse the so-called "state" theories of WM as opposed to "store" theories (see, e.g., Rose et al., 2014) and so differ from the ideas proposed and developed by Alan Baddeley (e.g., Baddeley, 2007; Baddeley and Hitch, 1974). One aspect of this distinction is that the notion of "store" suggests one location to which various types of information are imported, whereas the notion of "state" suggests that representations are distributed throughout many brain regions and are activated by attentional processes. I would classify the Craik and Lockhart (1972) view of PM as a state theory, given our suggestion that continued attention paid to encoded features—e.g., perceptual, phonemic, or semantic in the case of verbal items—was synonymous with the items being "in PM." This notion was closely tied to the general LOP framework, however, with the function of PM essentially restricted to holding information in a highly accessible state at a given "level" of processing.

Before attempting some characterization of the roles of representation and control in WM, I will list the essential aspects of the construct as I see them. A group led by Klaus Oberauer and Stephan Lewandowsky recently proposed a useful set of benchmarks for models of STM and WM (Oberauer et al., 2018). They set out some 20 major characteristics of PM and WM that theorists should consider in their models. My own list is shorter but overlaps with theirs along several dimensions; it is essentially a list of characteristics of WM that distinguish that construct from LTM:

1. *Information is in conscious awareness*
   We are also aware of our perceptions, so one role of WM is to prolong perception and so maintain important information in a state of action-readiness. The WM system can also act to hold and manipulate information retrieved from LTM.
2. *Limited capacity*
   The limit is basically attributable to limited attentional resources, although capacity can apparently be increased by making use of learned rules and

organization inherent in the activated representations—a phenomenon known as "chunking."

3. *Very rapid forgetting once attention is removed*
   This follows from the idea that retention in WM depends on attention, although it seems likely that items dropped from attention can still be retrieved for a time due to their primed representations in LTM.
4. *Coding is flexible*
   That is, the observed WM code depends on what is being attended to, but some features may be more amenable to maintenance than others—e.g., output response systems such as speech.
5. *WM involves executive functions*
   This feature relates WM to cognitive control and fluid intelligence.

Commenting briefly on these five points, although I list *conscious awareness* as the most salient characteristic differentiating WM from LTM, there is not a great deal to say about this ultimate mystery of cognition. Clearly, consciousness is invoked primarily in situations where reflex or automated responding would not be adaptive, or when choices must be made about competing courses of action. Such choices often entail the coordination of current perceptual inputs with retrieved relevant knowledge. Consciousness therefore co-occurs with decision-making and thinking; it also occurs when retrieved representations must be integrated or compared in novel ways, and as an accompaniment to recollection, both in recall and recognition. To focus on WM, we are conscious of the material held, and also of the operations performed on the material for the purpose of overcoming habit or for the selection of appropriate actions.

My assumption regarding *limited capacity* is that this obvious feature of WM is attributable to our limited span of attention—in terms of how much mental content can be apprehended at any single time, as opposed to how long in time we can concentrate on a given topic. The notion of span of apprehension has been around for some time in experimental psychology (e.g., Cattell, 1885) but has been neglected recently (with exceptions, e.g., Dixon and Shedden, 1993). The notion of span of apprehension is similar to the phenomenon of subitizing, in which individuals can make rapid and accurate estimates of small numbers of objects in the visual field. Subitizing, in turn, has been linked to WM capacity (e.g., Tuholski et al., 2001). In fact, Randy Engle and his colleagues have focused for many years on the concept of "working memory capacity" (WMC), typically measured by one or more complex span procedures. In their view WMC is strongly related to executive attention, which they propose to be domain-free but which works in concert with domain-specific storage and processing components (Kane and Engle, 2002). In turn, WMC reflects frontal lobe processing and underlies individual differences in fluid intelligence. Other prominent researchers who equate WM with attention paid to both recently perceived and recently retrieved information include

Nelson Cowan (e.g., 1999, 2001) and Klaus Oberauer (e.g. 2009). Both Cowan and Oberauer distinguish between a limited number of items held in the focus of attention (four in the case of Cowan, 1999, and only one in the case of Oberauer, 2009), and a few further items that can be accessed and recalled as required. These further peripheral items are regarded as being activated representations in LTM; given this, it is interesting to speculate on the type of coding they utilize, and I will return to this question in a subsequent paragraph. A final point about capacity is that it is generally considered that WM can hold "chunks" of information; that is, the system makes use of cases in which elements have been combined to form new units. For example, whereas the span for random letters may only be four or five, if the letters are grouped into well-known combinations such as BBC, CIA, and MRI, the capacity will now be around four chunks, composed of 12 individual letters. This finding emphasizes the important point that WM capacity is not some fixed measure of attention, but is attention in interaction with aspects of well-processed knowledge (see also Logie, 2003). So whereas WM may in some cases reflect attention to relatively raw perceptual information, the more usual situation is one in which WM holds information that has already been interpreted by the cognitive system.

If retention in WM is essentially equivalent to "attention paid to LTM representations," forgetting from WM should theoretically be dramatically rapid once attention is diverted elsewhere. The evidence suggests a gentler decline, however. One example comes from the Peterson paradigm (Peterson and Peterson, 1959) in which recall of three unrelated letters typically falls to 10% after 30 seconds of interpolated activity. This relatively gradual fading may reflect a decline in short-term priming of established LTM representations, but it may also reflect some covert rehearsing of the items when participants know that they must soon retrieve as many items as possible. This approach was explored by Muter (1980) who presented three letters to participants to recall after a 2-second interval on receiving the prompt LETTERS. On 17% of the trials (the "counting task") the three letters were immediately followed by a random three-digit number, and participants were trained that when digits appeared they need not recall the letters but should count backwards in threes from the presented number until the next trial started. However, on only *one* trial (around trial 100) the prompt LETTERS was shown unexpectedly after 4 seconds of counting. In this instance, recall level dropped to 13%, compared to 80% in a second study in which participants were informed that letter recall *would* occasionally be required after a few seconds of counting. So in Muter's experiment, forgetting from WM was dramatically rapid once attention was removed. Other points include the idea that after attention is removed from an item held in WM it seems possible to "rescue" its fading trace and reinstate it in the focus of attention. This phenomenon is referred to as "refreshing" (e.g., Barrouillet et al., 2004). Nathan Rose and I have argued that refreshing is basically equivalent to retrieval of items from SM (Rose and Craik, 2012); if so, are items retrieved in terms of their semantic characteristics or by some other means? I return to this point later. As a final point on forgetting, the LOP approach suggests that the rate of fading once attention is removed in WM should depend on the type of processing operations carried out on WM items, with slower fading, and thus better chances of refreshing, for items processed semantically or elaborately.

I have suggested that there is no one constant *type of encoding* in WM, but rather that WM coding is "flexible" depending on task requirements and the characteristics of the items to which attention is directed. It may be, however, that some features are easier to maintain in attention than others. For example, it seems easier to maintain verbal items (e.g., letters, words, and numbers) in terms of their phonology or articulatory properties than in terms of visual or semantic characteristics, possibly because we have a well-learned system of output responses for verbal materials, making them less costly to maintain in processing terms. In turn, this means that WM for verbal material typically appears phonemic in nature, although clearly other features can be maintained and manipulated depending on task demands. Returning to the idea of "refreshing," it seems at first that if refreshing entails retrieving recent WM items from SM, the retrieved information would be semantic in nature. This does not appear to be the case, however. Neither Rose and Craik (2012) nor Bartsch et al. (2018) found any evidence of semantic encoding in WM after refreshing. It may therefore be that participants refresh WM for verbal materials by retrieving recently dropped items from SM by means of their fading phonemic features. Alternatively, items may be retrieved from SM using semantic information but then reinstated in WM in terms of their phonemic features. Of course, other types of stimuli, such as visual patterns or auditory tones, *will* be held in WM by means of their appropriate perceptual characteristics. And I assume that WM encoding *can* be semantic in nature if the processing task involves judgments of meaning. One example could be a task in which a sequence of words (e.g., knife, house, car, stereo) must be re-ordered mentally in terms of their likely monetary value; another could be an n-back task in which targets are defined as words 2-back in a long series that belong to the same semantic category as the current word.

Much of the research effort on WM has dealt with letters, words, and numbers, but another influential line has explored visual working memory (VWM) using patterns of colored squares as material (e.g., Luck and Vogel, 2013). In their paradigm, participants are shown a sample array of colored squares for a brief interval, followed by a second array after a delay that is typically less than 1 second; the participant's task is to decide whether the two arrays are identical or if the second array includes a changed item. If WM is, indeed, a general cognitive resource involving attention paid to a wide variety of representations, common principles should be involved regardless of the material attended to and worked on. Luck and Vogel (2013) define VWM as the active maintenance of visual information to serve the needs of ongoing tasks, with three key components being first that the information held is visual in nature, second that VWM involves active maintenance, and third that the representations must be used in the service of broader cognitive tasks (Luck and Vogel, 2013, p. 392). This seems to me like an excellent fundamental definition, although I would broaden their first component to include a greater variety of representation types. I would also add the ideas that maintenance is accomplished by deploying attention (or "processing resources") to relevant perceptual, motor, or higher-level abstract representations, and the notion that individuals are consciously aware of the contents and operations involved in WM activities. Finally, it seems crucial to emphasize that WM maintenance is an *active* process, not a passive storage mechanism.

The involvement of *executive functions* or controlled attention is defining feature of WM, and the aspect that differentiates the active "working" memory system (e.g., Baddeley and Hitch, 1974) from the relatively untransformed maintenance characteristics of PM in older experiments. Controlled attention is required to override over-learned "prepotent" habits in the Stroop and Simon tasks, and to resist the interfering effects of extraneous stimuli that act to disrupt some ongoing task. Engle and his colleagues have, in fact, defined WMC as the ability to keep representations and operations active in the face of interference and distraction (Engle, 2002; Engle et al., 1999). I would argue that all current models of WM have a role for executive processes both in terms of specific operations performed on the items held in temporary storage and in terms of higher-level managerial functions such as integration, coordination, supervision, decision-making, and response selection (Baddeley and Hitch, 1974; Cowan, 1999; Engle, 2002; Oberauer et al., 2000). The further general assumption is that such attentional control/executive functions are carried out by frontal lobe processes in interaction with specific processes situated in posterior regions of the brain (D'Esposito and Postle, 2015; Ruchkin et al., 2003; Unsworth and Robison, 2017).

Other higher-level WM functions include the ongoing need for comprehension of successive perceptual inputs. Again, this arguably involves transactions between the incoming information and relevant stored representations, with WM supplying cognitive control to the transactions. A further increase in complexity occurs when there is a need to augment and enrich incoming information for the purposes of learning and successful subsequent memory. This is the function known as elaborative processing in the levels of processing framework. Beyond these processes of item elaboration, effective learning procedures often involve the establishment of associative links between inputs or between new inputs and aspects of the existing cognitive environment. Processes of organization (e.g., Mandler, 1967; Tulving, 1962) and integration to established bases of knowledge provide further higher-order examples. Thus, WM processes are clearly involved in such complex cognitive functions as learning, concept formation, thinking, reasoning, and decision-making. When considering these higher-level cognitive functions it is admittedly difficult to separate the construct of WM from such other constructs as executive functions and cognitive control. In my opinion all of these various labels refer to constellations of cognitive processes that in all likelihood are *not* clearly separable, but reflect collections of processes that are mobilized to perform some needed function. To keep the study of WM within reasonable bounds and restrain the concept from being simply a proxy for "cognition," it is probably sensible to restrict the term to situations in which temporary information storage is central to the task in question.

Levels of processing effects in working memory?

Earlier in this chapter I discussed experiments that showed strong benefits of deeper, semantic processing over shallow processing in STM tasks (e.g., Craik and Levy, 1970; Levy and Baddeley, 1971; Levy and Craik, 1975; Wickens, 1973), and also concluded that such semantic benefits were attributable to the "SM component of short-term retention" (Craik and Levy, 1970). Is there evidence for semantic or levels of processing effects in WM performance, and, if so, should such effects also be attributed to retrieval from LTM? Nathan Rose investigated this possibility in a series of experiments conducted at the Rotman Institute with Bradley Buchsbaum and myself (Rose et al., 2014; Rose and Craik, 2012). In one experiment in the 2014 article we presented a single word on each trial for later recall; the word was processed either shallowly ("Does the word contain the letter E?") or deeply ("Does the word represent a living thing?") followed by a 10-second retention interval before a recall attempt. The interval was either empty, allowing the participant to rehearse the word and so maintain it in WM, or was filled by either an easy math task or a difficult math task. Our reasoning was that the easy task would allow at least some rehearsal and refreshing if needed, whereas the difficult math task would consume essentially all of the participant's attentional capacity, thereby eliminating rehearsal and arguably the word's presence in WM. We thus argued that recall after as little as10 seconds of the difficult math task must be from LTM. After 120 trials participants were engaged in a distractor task for 10 minutes, followed by a final free recall test for all 120 words.

Figure 6.5a demonstrates that initial (10-second) recall from WM shows essentially perfect recall in the empty interval (rehearse) condition, and progressively lower levels of recall in the easy and hard math conditions. More interestingly, the benefit of initial deep over shallow encoding gets larger from rehearsal, through easy math, to the hard math conditions; the interaction between deep/shallow processing and the delay condition was highly significant ($p < 0.001$). The final free recall results (Figure 6.5b) shows a significant benefit to deep over shallow encoding for all delay conditions. One further result of interest is that final recall proportions were significantly smaller after rehearsal than after the two math conditions. This result echoes the previously discussed findings of negative recency and poor final recall of words recalled first in immediate recall (Craik, 1970). As argued earlier in

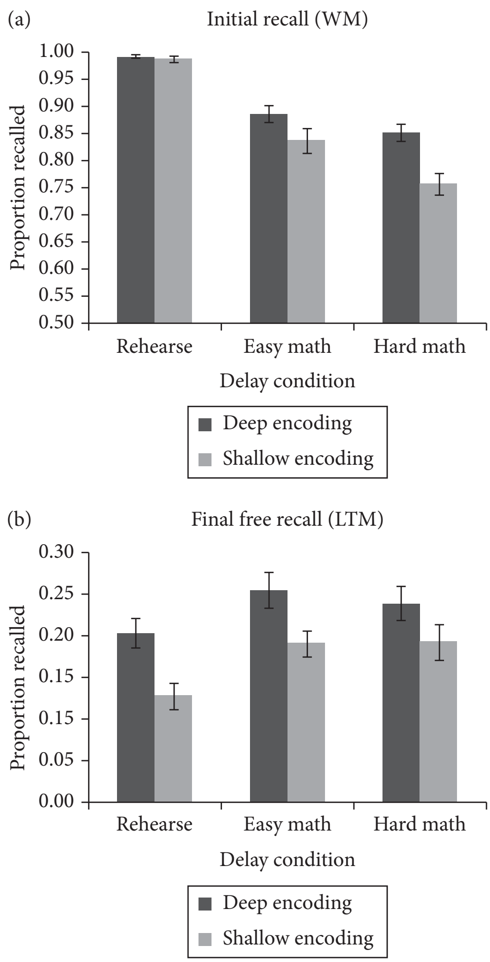

Fig. 6.5 (a) Probability of recalling a single word after deep or shallow encoding. Recall followed a 10-second delay interval that was either unfilled to allow rehearsal or was filled with either easy math or hard math. (b) Proportions of words recalled in a final recall test as a function of encoding condition and delay condition. WM = working memory; LTM = long-term memory.

Reproduced from Rose, N. S., Buchsbaum, B.R., Craik, F. I. M Short-term retention of a single word relies on retrieval from long-term memory when both rehearsal and refreshing are disrupted. *Mem Cognit*. 2014 Jul;42(5):689-700. doi: 10.3758/s13421-014-0398-x with permission from Springer Nature.

this chapter this result supports the conclusion that maintenance rehearsal using phonemic information is associated with low levels of subsequent retention.

So, are there LOP effects in WM? The effects are clear in the final recall test (Figure 6.5b) and in the hard math condition of immediate recall (Figure 6.5a); they are also present in reduced form in the easy math condition. One way of interpreting this pattern of results is to argue that the beneficial effects of semantic processing are found only when the words are retrieved from LTM (LTM in Figure 6.5) as opposed to WM. The suggestion is therefore that final recall (some 30 minutes after presentation) clearly depends on retrieval from LTM, and also that initial recall after 10 seconds of hard math, and on some occasions after easy math, has relied on retrieval from LTM. In the older terminology these LTM effects were referred to as retrieval from the SM portion of immediate recall. In fact, Unsworth and Engle (2007) have suggested that WM comprises both PM and SM components; the present result could then be tentatively described as showing that LOP effects were found only in the SM portion of WM. An alternative account drawing on the models of WM proposed by Cowan (2005) and Oberauer (2000) is that semantic effects are restricted to items still "in WM" but outside the region of focal attention. This account thus suggests that verbal items in the focus of attention are held in terms of their phonological or articulatory properties, and that the semantic properties conferred by deep processing at encoding have no extra effect. The semantic properties are clearly there, however, as shown by the advantage to deep processing in final recall.

A remaining puzzle concerns the nature of encoding dimensions in WM. As stated earlier, my preference (in line with current state models of WM) is the suggestion that WM connotes attention to a wide variety of representations, including presumably semantic representations. So if this is so, why are LOP benefits apparently restricted to items that are not in focal attention? One possible answer is that it is most efficient to maintain verbal items in WM by rehearsing their motor output features (that is, their articulatory properties) and that each item's further encoded features (e.g., font size, color, place on a page for visual items; voice quality, loudness, etc., for auditory items; semantic characteristics for most items) are present but not utilized by the rehearsal processes. A fuller understanding of these puzzles will depend on using a wider selection of materials, encoding dimensions and experimental paradigms.

Working memory: One construct or a set of separable abilities?

WM has been measured in a number of ways, principally using tasks that involve holding and constant updating of the material held in response to changing inputs. These include a variety of "n-back" tasks in which participants are presented with a long series of letters, numbers, words or other visual or auditory symbols. The task is to detect instances in which the current stimulus is a repetition of one that was previously presented exactly "n-back" in the series, where n is typically 2 or 3. Another popular task is reading span or sentence span (Daneman and Carpenter, 1980) in which participants read a series of sentences and must also retain the last word of each sentence to be recalled at the end of the series. Measured in this way, reading span in college students ranged from two to five final words recalled, and these individual differences correlated with other measures of reading comprehension, in contrast to more traditional measures such as digit span and word span which did not correlate with comprehension (Daneman and Carpenter, 1980). Other variants of this task include ones in which participants must verify the truth of each stated sentence, as well as remember each last word—e.g., "Kittens are often kept as pets," "London is the capital of France," then recall "pets, France." Salthouse and colleagues devised computation span variants in which participants see or hear simple arithmetic questions such as "Six minus two equals?" and must then select the correct answer from three alternatives (4, 2, 3) and also remember that answer as one of an ongoing series (Salthouse and Babcock, 1991). Other similar tasks were designed by Turner and Engle (1989). In one task participants read a series of sentences; each sentence was followed by a digit, and the task was to recall the digits at the end of the series. In a second variant, participants solved simple arithmetic problems; each problem was followed by a word, and participants recalled the words at the end of the series.

Do these different WM tasks all measure one common WM construct? Following the notion that WM reflects attention paid to the representations and processes relevant to each specific task we can say that individual differences will depend both on the capacity and control of the person's attentional system, and also on his or her knowledge and skill associated with these specific representations and processes. The latter component presumably reflects the knowledge and skilled procedures acquired and maintained over a lifetime, and may be regarded as being relatively stable at any one point in time. The notions of attentional capacity and control, however, may reflect some essential individual difference of executive functioning, but the effectiveness of attentional control processes clearly also varies as a function of arousal, fatigue, engagement and effort, as well as with familiarity and practice in dealing with the task at hand. The inability to maintain attention to some designated activity has itself garnered considerable scientific attention recently under the headings of goal neglect and mind wandering (e.g., Duncan, 1995; Kane and Engle, 2003; Mason et al., 2007).

Given these many sources of variability, error, and individual differences it may be more reasonable to regard WM as a loosely integrated set of related abilities, rather than as a unitary construct. In turn, this approach suggests that the strength of correlations among different WM tasks will vary as a function of the similarity of the representations and procedures involved, although there may, indeed, be some abstract latent construct of WM reflecting individual differences in attentional control. The question of whether WM is a domain-general construct or exists as a set of domain-specific processing and storage abilities is a central one for cognitive psychology and cognitive neuroscience. For long enough I was happy to accept the idea of a general construct of WM, although WM tasks clearly involve a variety of different materials. Our work with the alpha span test planted some seeds of doubt on this perspective, however. The alpha span test (Craik et al., 2018a) is one in which participants are presented with short lists of unrelated nouns and are asked to reproduce the list in correct alphabetical order. Given that the test involves both storage and processing of the material held it seemed to be a decent measure of WM. We included the test in two studies of aging carried out at the Rotman Institute, and in both studies alpha span correlated most strongly with measures of verbal ability (vocabulary level and tests of reading ability) rather than with other cognitive measures. This finding led me to adopt the view proposed in this chapter that WM reflects attention paid to aspects of one or more knowledge systems. It seems entirely likely that attentional processes themselves are "domain-general" and reflect one common resource, but cognitive abilities and cognitive skills reflect specific natural aptitudes, plus individual differences in learning and practice, and as such are likely to be at least somewhat independent from each other. This general view suggests that different WM tasks may not correlate well, and this result has been reported by several investigators.

For example, a study by Daneman and Tardif (1987) examined the role of WM in reading ability and discovered that verbal and spatial WM tasks did not correlate well. They therefore concluded that verbal WM and spatial WM are separate processing capacities. This conclusion was also reached by Shah and Miyake (1996) who conducted tests of participants' general verbal and visual abilities, and also tests of verbal WM (reading span) and visuo-spatial WM (spatial span). Their basic findings were that reading span correlated significantly with a measure of general verbal ability ($r = 0.45$) and spatial span correlated significantly with spatial ability ($r = 0.66$), but reading span did not correlate with spatial ability ($r = 0.12$) and spatial span did not correlate with verbal ability ($r = 0.07$). Reading span and spatial span themselves did not correlate significantly ($r = 0.25$, $p > 0.10$) bearing out Daneman and Tardif's (1987) results. Shah and Miyake concluded that their results were consistent with the view that visuo-spatial and verbal WM draw on separate pools of processing resources.

The same result was obtained in a similar study run in my laboratory in collaboration with Ellen Bialystok and Nathan Rose. Our idea was again that WM may be thought of as controlled attention (which may be domain-general, e.g., Kane et al., 2004) applied to representations of underlying specific abilities. We asked 50 young adult participants to complete three measures of general verbal ability and three measures of general spatial ability to establish individual differences in these aspects of cognitive performance. The same participants performed three tests of verbal WM and three tests of spatial WM. Our general prediction was that performance on the verbal WM tasks would correlate with verbal ability but not spatial ability, and similarly that spatial WM performance would correlate with spatial ability but that there would be few, if any, cross-domain associations. To provide a general measure of verbal processing the raw data from the three verbal WM tests were converted to T-scores to have all measures on the same scale, and were then combined to form a composite measure. The same procedure was applied to measures of spatial WM, verbal ability, and spatial ability. Finally, the composite measures were correlated to yield the pattern of inter-correlations shown in the top half of Figure 6.6.

The figure shows that we essentially replicated the results of Shah and Miyake (1996); each specific measure of processing related strongly to its parent ability but not at all to cross-domain abilities. In this case the composite measure of verbal ability did correlate significantly with the composite measure of spatial ability, suggesting related individual differences in overall intellectual ability; but, crucially, there was no trace of a relationship between verbal and spatial processing, so no evidence for an overall general construct of WM.

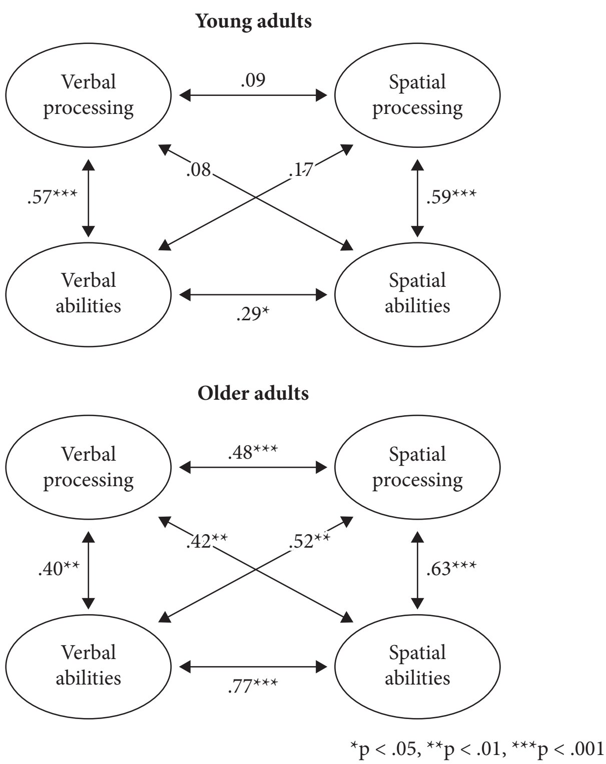

Fig. 6.6 Correlations among composite measures of verbal abilities, spatial abilities, verbal processing (verbal working memory), and spatial processing (spatial working memory). The top panel shows results from a group of 50 young adults, and the bottom panel shows results from a group of 50 older adults (Craik, Bialystok, and Rose, unpublished data).
Courtesy of Craik, Bialystok, and Rose.

We repeated the same experiment on 50 older adults in their sixties with very different results. The bottom half of Figure 6.6 shows that in this group of adult volunteers from the community everything now correlates with everything else! This result is in line with a "dedifferentiation" view of cognitive aging, which suggests that cognitive abilities in younger adults are generally rather specific and uncorrelated but that as people age, abilities show a progressive tendency to couple and correlate, tending towards one general factor of cognitive ability. This view forms part of a larger lifespan theory of cognitive development suggesting that linguistic terms, categories, and concepts tend to be global and undifferentiated in young children but gradually differentiate into more specific representations as the child develops. Baltes, Lindenberger, and their colleagues (e.g., Baltes et al., 1980; Lindenberger and Baltes, 1994; Lindenberger and von Oertzen, 2006) have suggested that the process reverses in the course of normal aging such that older adults maintain good access to higher-level concepts but gradually lose accessibility to names and other specifics (see Craik and Bialystok, 2006).

The notion of age-related dedifferentiation has received support from some studies—for example Hülür et al. (2015) from 419 individuals in the Seattle Longitudinal Study. But other studies have failed to support the idea (e.g., Tucker-Drob, 2009; Tucker-Drob et al., 2019 in a meta-analysis involving 30,000 individuals). Another line of evidence has examined specificity and coupling of brain structures as a function of aging. Here there is evidence that representations of visual categories are less well differentiated in the older brain (Park et al., 2004) and also that "white matter microstructures across brain tracts become increasingly correlated in older age" (Cox et al., 2016). The notion of dedifferentiation is thus still one of active debate.

The results from younger adults shown in the top half of Figure 6.6 are in line with the idea of separate processing resources—separate types of WM—for verbal and spatial material. The growing consensus in the field, however, is that specific WM capacities for verbal, spatial, and numerical information themselves correlate to form a latent construct of general WM capacity at a higher level. With reference to the opposing results reported by both Daneman and Tardif (1987) and Shah and Miyake (1996), Kane et al. (2004) suggested that these studies may have obtained the results they did, first because they used single measures of verbal and spatial WM, and, second, because their undergraduate participants formed a rather homogeneous group with little variability between participants. In the case of the study shown in Figure 6.6, the younger participants were again undergraduates whose measures on the various tests do, indeed, show less variability than measures of the older group. We did, however, have several measures contributing to the components shown in Figure 6.6. Different tests and different samples of participants may somehow result in different patterns of relations.

Evidence in favor of one overall construct of WM comes from several recent studies—which mostly do also report some degree of independence of (e.g.) verbal and spatial WM at a lower level of analysis. For example, Oberauer et al. (2000) conducted a large-scale study (N = 128 young adults) involving tests of verbal, numerical, and spatial WM. They found no differences between verbal and numerical WM, but the spatial WM tests gave rise to a separate factor. Nonetheless, a four-factor measurement model showed a strong correlation between the verbal–numerical factor and the spatial factor, so the general conclusion favored the concept of WM as one general processing resource (Oberauer et al., 2000, p. 1041). The researchers also endorsed the view that intellectual abilities can be structured hierarchically, possibly with controlled attention serving as the highest-order unifying construct with strong relations to the notion of fluid intelligence (*Gf*) as also proposed by Engle, Kane, and colleagues (Engle et al., 1999; Kane & Engle, 2002; Kane et al. 2004). The notion that specific WM constructs are components of general intelligence was also illustrated by Oberauer et al. (2000). Their factor analysis yielded three main factors, representing verbal WM, spatial WM, and speed of processing; all three factors correlated strongly with components of a general intelligence test. Subsequent studies have also largely endorsed the view that relatively specific measures of aspects of WMC do themselves correlate at a higher level, which in turn may be identified as *Gf*, probably mediated by frontal lobe processes (e.g., Fukuda et al., 2010; Meier, 2019; Redick et al., 2012a, 2012b).

The notion of a hierarchical model of WM was explicitly proposed and elaborated by Schmiedek, Lövdén and Lindenberger (2014). Using a variety of WM measures, including complex span and n-back tasks, they interpreted their results as illustrating a conceptual hierarchy in which these and other specific *tasks* formed the lowest level. The next level up comprises *paradigms* such as complex span, updating, *n*-back, and processing speed; these paradigms contribute, in turn, to the *construct* level of WM. Schmiedek and colleagues also propose an even higher, more abstract *psychometric level* to show how higher-level cognitive abilities (e.g., reasoning, problem-solving, decision-making) fit their general scheme. This hierarchical approach fits my own thinking very comfortably and I happily endorse it—“levels of working memory” sounds good to me! Clearly, much remains to be worked out—for example, the differences in tasks and participant samples that underlie the very different pattern of relations contrasted in the top and bottom halves of Figure 6.6. Additionally, I have reservations about the idea of a processing hierarchy being *controlled* from above by some real *g*-like entity. The alternative is the suggestion (e.g., Kovacs and Conway, 2016) that *g* is a purely theoretical construct that *emerges* from the overlap in processes necessary for the successful completion of lower-level cognitive tasks, rather than a real entity that *causes* correlations among such tasks. This point is pursued in the final chapter. Nonetheless, a hierarchical scheme such as the variant proposed by Schmiedek et al. (2014) does provide a sufficiently general framework that can accommodate both state models and the more structural “buffer” models developed by Baddeley and Hitch (1974), Baddeley and Logie (1999), and others.

Short-term retention: An integrated view

Throughout this book I have emphasized the interactions among environmental inputs via perception, stored representations of knowledge gleaned from many past experiences, and appropriate actions to modify the external environment adaptively. WM functions play a key role in these interactions; in a sense, they serve as a central meeting place and clearing house to ensure that incoming information is interpreted effectively in terms of past experience and that appropriate action is taken in light of that interpretation (see Engel et al., 2013, for further discussion of the crucial interactions between perception and action). I have also suggested that commonalities in perceptual experiences coalesce to form multimodal representations of knowledge at increasingly higher and more abstract levels (see Figure 3.3). In turn, these representations act to interpret further inputs and are both modified by changes in perceptual inputs (in a sense to "harmonize" the relations between perceptual interpretation and appropriate action) and are *differentiated* to account for the differing significance of inputs in different contexts.

In this dynamic mix of input, central, and output interactions it is often beneficial to hold input information temporarily—to aid comprehension, for example, in that later parts of a sentence can clarify the meaning of earlier parts, or it may be adaptive to hold an action plan temporarily until the time and context are optimal for the action to be executed. So while the essential function of short-term retention may be the prolongation of perception to enable adequate comprehension and the selection of appropriate action, the information "held" in this way is thus likely to change from sensory to perceptual to cognitive as processing interactions proceed. The cognitive aspects are contributed by the activation of stored representations in LTM—the same multimodal representations that were formed *from* perceptual experiences and which later mediate the experience and interpretation of current ongoing perception (D'Esposito and Postle, 2015).

As argued in this chapter and by many recent theorists, short-term retention may be regarded as a dynamic mix of processes elicited by current perception and processes derived from stored past experiences; this evolving mixture is monitored and guided by processes of controlled attention. The incoming percept may be held briefly (in WM) and translated into appropriate output codes; these, in turn, may also be held in WM until a response is required. Digit span and word span are examples of such straightforward mappings. In most instances further processing is carried out on the stored material, however, in which case WM performance will be affected by the participant's familiarity and ability with the type of processing required. One example of this is the alpha span task, in which participants are presented with a short list of common words and must repeat them back in correct alphabetical order. As mentioned above, performance on this task correlates with the person's vocabulary knowledge and other tests of verbal ability (Craik et al., 2018a). I would therefore say that while individual differences in WM reflect differences in attentional capacity, they also reflect differences in relevant knowledge and in the skilled computational abilities associated with the processing demands of specific tasks. This attention-based view of WM is obviously compatible with the views of Cowan (1999), Engle et al. (1999), and Oberauer (2002), but it is worth mentioning that it is also compatible with the "buffer" models of Baddeley and Hitch (1974) and Logie (1995). The constructs of articulatory loop, phonological store, visuospatial sketchpad, and visual cache may be understood in terms of attention paid to information in the various modalities rather than in terms of structures to hold different types of information. The articulatory rehearsal loop, indeed, is already a dynamic process dependent on continuous attention. The episodic buffer (Baddeley, 2007) may also be re-construed in terms of attention paid to a variety of recently activated modality-specific and modality-free representations. And, finally, the central executive in the multicomponent model seems essentially identical to notions of attentional and cognitive control.

The present chapter has provided experimental examples of work from my laboratory over the years ranging from early work on dichotic listening (differential attention to auditory inputs) through work distinguishing the characteristics of verbal information "held in PM" in phonemic terms from information "retrieved from SM" by means of semantic cues, to more recent studies exploring the constituents of WM. Although conducted for a variety of specific reasons at the times they were carried out, I believe that the findings fit comfortably into the present framework couched in terms of attention paid to a variety of different perceptual inputs, plans for motor outputs, and activated representations of past experiences at different levels of specificity-abstraction. A final point is to repeat my endorsement of the hierarchical view of WM suggested by Schmiedek et al. (2014) and others. In this formulation, evidence for specific forms of WM (e.g., verbal, spatial, numerical) is obtained from specific tasks and paradigms, but there is also some overarching commonality among the specific forms of WM—perhaps contributed by the common application of domain-free attentional processes. At this high level of abstraction, the construct of WM has much in common with the construct of fluid intelligence—both reflecting the involvement of executive control processes mediated by the frontal lobes.

7
Aging I
Early Studies and Theoretical Views

Although my main research activities have focused on theoretical and empirical studies of human memory, an important secondary topic has been the effects of aging on attention, memory, and cognition; this work is described in the present chapter and in Chapter 8. The ideas and experiments were formulated in the same processing framework developed for memory studies, and I would like to think that there was some cross-fertilization of concepts and methods between the two areas. In essence, the evidence shows that there *are* substantial age-related impairments in memory but that the impairments are much greater under some conditions than others. My research program has been guided largely by attempts to understand these differences. As described in this chapter, I have proposed that two major biological age-related changes underlie many changes in memory and cognition. One is a reduction in available processing resources and the other is a (possibly related) failure to perform "self-initiated activities" when appropriate mental processes are not sufficiently supported by influences from the external environment or from well-learned habits and routines. In my view. the resulting impairments in memory and cognitive control stem largely from age-related inefficiencies in frontal structures and functions, although other brain areas are undoubtedly also involved. This chapter and the next serve to unpack these cryptic comments, illustrated by experimental findings from my own laboratory over the years.

Some personal history

When I was a graduate student at the University of Liverpool in the 1960s, our research group was visited by an eminent scholar from London—a Professor Fry, as I remember. Our group was made up of young graduate students, and when we were introduced as researchers of the aging process, the professor remarked "Hmm, studying it from some distance it seems!" Less true today, alas! However, living through the aging process does at least afford the researcher the luxury of checking his or her earlier theoretical pronouncements against the present empirical reality. I became involved in research on aging rather accidentally in fact—through the academic grapevine rather than through a deliberate choice. James Drever, the Chair of Psychology at the University of Edinburgh where I did my

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undergraduate degree, was friends with Alistair Heron, the Director of a Medical Research Council research group studying aspects of the aging process. Professor Drever thought that I would be a good fit, and so recommended me to Dr. Heron. The Medical Research Council Unit was attached to the Department of Psychology in Liverpool University, and was in a way the successor of the very successful group at Cambridge led by Alan Welford. However, the mandate of the Liverpool group was to study more practical aspects of aging, especially those relevant to the needs of an aging workforce. Dr. Heron was taking on graduate assistants who not only worked on general projects that the Unit was engaged in, but who could also pursue their own research towards a PhD. He was interested in the idea that performance levels in older workers may be artificially restricted by a lack of confidence in their abilities—especially when being retrained in middle age for a new type of vocational position. So Alistair Heron suggested that I study this problem experimentally.

After arriving at Liverpool I carried out a couple of studies within the framework of Rotter's Level of Aspiration Theory—a way of comparing the goals people set with their actual level of performance—but I found the ideas rather vague and the measures unsatisfactory. Broadbent's theory of attention was more to my taste, so I turned to experiments using dichotic listening and to other dual-task paradigms in which participants attempted to detect faint tones on an auditory channel while simultaneously learning verbal material on a visual channel. This second paradigm followed an interesting study by Martin Taylor and colleagues (Taylor et al., 1967) in which they proposed that processing capacity in dual-task experiments could be estimated by measuring the discrimination ability associated with each task by the signal detection metric d', and then adding the values d'^2 for two discrimination tasks performed simultaneously. By this method they found that shared capacity was approximately 85% of capacity measured from performing each task alone, and suggested that the missing 15% was the amount needed to manage division of attention between the two concurrent tasks. In my version comparing younger and older adults, the "management cost" rose from 15% in the young group to 30% in the old group. I still think this is an interesting result, but I never published the experiment formally, partially after being savaged by a discussant when I presented the study at an American Psychological Association (APA) meeting. The discussant (whose name I have mercifully repressed) was a sort of high-church psychophysicist whose belief system included the principle that d' should be used only to measure the discrimination of pure tones. In his remarks he was withering about another presenter who had worked with other less pure auditory stimuli "and then," he continued, "there was the person who had calculated d' using *memory* for WORDS … " Words, indeed, failed him, and I slunk off in deep disgrace. However, the experiment piqued my interest in dual-task studies, and the interactions between attention and memory, so not all was lost.

Another early experiment, carried out with Alistair Heron, was a somewhat Pythonesque study in which we measured the digit spans of Liverpool citizens using Finnish digits—Finnish being a language unknown to the citizens in question. The point was to compare "digit span" using essentially meaningless sounds with digit span in English in different age groups, and the result was that spans in Finnish were equivalently low in the two age groups, but spans in English were substantially higher in the young group than in the older adults. So short-term memory for meaningless material showed no age differences, but younger adults could presumably chunk and encode meaningful material more effectively. We did publish this study (Heron and Craik, 1964) —in the *Scandinavian Journal of Psychology* appropriately enough. Another local study of aging conducted around the same time was one by Broadbent and Heron (1962) in which older and younger adults performed a number-checking task concurrently with a short-term memory task for letters. The major result of interest—and still of interest today—was that whereas the younger participants could perform the two task together reasonably well, the older adults chose to focus on one task or the other, while performing very poorly on the neglected task; an apparent case of an age-related decrement in dual-task performance (see later).

Memory systems and aging

In 1965 I moved from Liverpool to take up a faculty position at Birkbeck College (now fashionably streamlined to plain "Birkbeck"), a constituent college of the federal University of London. I had no obligation at Birkbeck to carry on research into problems of aging, and my research focus at that time was principally on the nature of short-term memory. I still continued some aging work, however, and had collected data in Liverpool that I was still working on. One set of experiments followed up on Waugh and Norman's (1965) suggestion that immediate recall of word lists drew on two separable memory stores—primary memory (PM) and secondary memory (SM). As described in the previous chapter, PM reflects those words, usually at the end of the list, that are still "in mind" and are typically recalled first. SM is essentially equivalent to "long-term memory," and consists of words and other events that were experienced some time in the past, have been dropped from conscious awareness, and so must now be retrieved.

Two experiments from my laboratory around that time attempted to document the different characteristics of PM and SM. Craik (1968b) endorsed the notion that immediate free recall of a word list involves two rather different mechanisms; first, a read-out of items from a limited-capacity PM, followed by a search process through a much larger SM. Experiments involving lists ranging in length from five to 20 words yielded the function $R = m + kL$, where R = number of words recalled, L = list length, and m and k are constants. I suggested that m = the number of words in PM and that k indexes the efficiency of the search process in SM. Evidence from several experiments showed that the capacity of PM was around 3.5 to 4 words, was independent of word length, and that this capacity did not change over the adult lifespan. The insensitivity to word length suggested that the "unit of storage" is *words* as opposed to phonemes or syllables, and that PM is thus "postperceptual" rather than being a peripheral sensory store. The suggested model for recall is shown in Figure 7.1. The idea is that when list length is only one, two, or three items, recall will essentially be perfect; so recall (R) will reflect list length (L) and the ideal function is R = L. But once PM capacity is exceeded, the recall function deviates from the ideal performance function and proceeds linearly but with a much lower slope, indexed by the constant k. The experiments reported by Craik (1968b) showed that k is unaffected by word length, increases when the words to be recalled are drawn from a limited set, and decreases from young adults to older adults. That is, retrieval from secondary memory is more efficient when the search process is constrained and supported by presenting words from a limited set (such as animal names or color names), and is less efficient as a function of aging. As noted earlier, m is unaffected by both age and word length.

A second analysis (Craik, 1968a) reported the qualitative types of errors that young adults made when recalling words of 1–4 syllables from lists ranging from 6

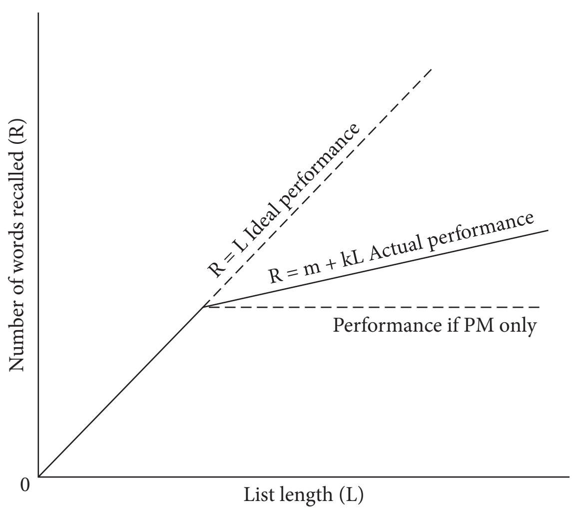

Fig. 7.1 Theoretical functions relating recall to list length (Craik, 1968b). PM = primary memory.

Reproduced from Craik, F. I. M. (1968b). Two components in free recall. *Journal of Verbal Learning & Verbal Behavior*, 7(6), 996–1004. https://doi.org/10.1016/S0022-5371(68)80058-1 with permission from Elsevier.

to 18 words. Errors were classified as being either acoustically related to a list word, semantically related to a list word, an intrusion from a previous list, or apparently random. They were also grouped according to when they were recalled, measured in five 2-second bins from the recall signal (0) to 10 seconds, a sixth response bin held errors made after 10 seconds. The percentage of sound-alike acoustic errors dropped from 55% in the first 4 seconds to 25% in the last two intervals, while the percentage of semantic errors plus intrusions from previous lists rose from 30% to 42% in the same intervals. A similar pattern emerged when considering errors as a function of output position in the participant's responses. Of errors made in the first three responses 66% were acoustic errors whereas semantic plus previous list errors made up 11%. The corresponding percentages for output positions 8 and later were 30% for acoustic errors and 19% for semantic errors and previous-list intrusions.

This pattern of errors is consistent with the notion discussed in Chapter 6 that words held in PM are encoded in phonological or articulatory terms, and are often recalled first. Later responses are more likely to be semantic confusions or words presented in a previous list; such errors were considered to be recalled from SM. The attribution of acoustic coding to "short-term memory" and semantic coding to "long-term memory" is in good agreement with the results of Baddeley (1966a, 1966b), and does suggest that immediate recall reflects retrieval from two different memory systems; further, that PM is not affected by the aging process, whereas encoding and/or retrieval processes associated with SM do decline in the course of aging. These findings seem in good agreement with a memory systems perspective (e.g., Tulving, 1983), but it is also possible to argue (e.g., with Jacoby, 1983) that the separate systems in question are more simply two different representational codes, acoustic and semantic for PM and SM, respectively. Words may be represented by both acoustic/articulatory and semantic attributes shortly after presentation, but if the acoustic code is more transient, then later retrieval must rely on access via the semantic code. A second point concerns the evidence that, on the one hand, the PM component uses a "surface" code that is phonological or articulatory in nature and, on the other hand, deals with words rather than phonemes or syllables. At first this seems like conflating two levels of representation—acoustic and lexical—but it seems reasonable to argue that lexical and semantic knowledge bind each word into one cohesive unit which also embodies a short-lasting representation of its sound. In turn, sound may be an easier and more direct way to access the item; think of attempting to locate recently displayed objects pictured in black and white from a cluttered display of many similar black and white objects. If recently displayed objects glow red, but the color fades within a few seconds, it will obviously be easy to locate these objects while the color persists. After that time, wanted objects must be specified in terms that are more "semantic" in nature—e.g., in terms of their prototypical shape, their function or their categorical nature.

The 1977 Handbook chapter

I moved from London to Toronto in 1971 and devoted my research time largely to the evolution of the levels-of-processing (LOP) work, both in terms of theoretical discussions with Lockhart, Tulving, and others, and also in terms of an empirical program of experiments carried out mainly with Endel Tulving. However, in 1975 I received an invitation from the eminent gerontologist James Birren to write the chapter on age differences in human memory for the first *Handbook of the Psychology of Aging*, edited by Birren and Schaie (1977). I was flattered, but protested weakly that I had not worked on aging for several years. Birren responded to the effect that this is why he and his committee had thought of me—to survey the current field critically and objectively. Writing the chapter was a lot of work, but it has been quite influential, and also had the effect of re-awakening my interest in age-related differences in memory.

The 1977 chapter discusses age differences in short-term and long-term memory from the perspective of the PM/SM distinction described earlier. Within the SM literature the chapter covers encoding and acquisition processes, concluding that older people are less effective at carrying out the types of semantic and organizational processes that result in high levels of subsequent memory performance. In terms of retrieval processes the chapter highlights the finding that, whereas free recall of words dropped progressively from 20 seconds to 60 seconds, recognition memory showed no decrements across the same age range (Schonfield and Robertson, 1966). Further work showed that recognition memory is not *immune* to aging but, more broadly, that age differences are greater in recall (see also Craik and McDowd, 1987, and Danckert and Craik, 2013, discussed in Chapter 8). The more general conclusion was that "Older subjects appear to be at the greatest disadvantage relative to younger groups when little retrieval information is provided by the experimental situation. In this case, they must rely on self-generated reconstructive activities (e.g., Bartlett, 1932) to retrieve the items" (Craik, 1977a, p. 402). Clearly, this statement looks forward to the notions of "environmental support" and "self-initiated activities" proposed more formally several years later (Craik, 1983, 1986).

Two other approaches that were highlighted are the very innovative and informative studies by Harry Bahrick and his co-workers on very long-term memory for the names and faces of high-school colleagues up to 50 years later (Bahrick et al., 1975). Interestingly, results from this study of real-life memory echoed laboratory findings in that *recognition memory* for names and faces held up well for up to 25 years, whereas *recall* of the same information dropped off in less than a year. The second approach to memory and aging was an unpublished study exploring age-related differences in recall and recognition using the LOP paradigm. The experiment was an undergraduate thesis carried out at Erindale College (University of Toronto) by Sharon White, a very bright young woman who for family business reasons resisted my entreaties to pursue a career in academic research. The picture-perfect results are shown in Figure 7.2.

The encoding conditions comprised case, rhyme, or category decisions about single words, and also an intentional learning condition for further words. So participants expected a memory test for one-quarter of the words but thought they were simply making cognitive judgments about the remaining words. After the encoding phase, participants were first asked to recall as many words as possible from *all* conditions, and were then given a recognition test. Figure 7.2 shows a strong "levels" effect, higher performance on recognition than on recall, and an age-related performance decrement for recall and the learn/recognition condition but no age differences for the three recognition conditions involving incidental learning. The recall results followed predictions, but the recognition results were unexpected. I would now say that the pattern of results reflects an age-related decrement in both encoding and retrieval processes but that these decrements can be "repaired" by the provision of incidental orienting tasks at encoding and a recognition test at retrieval. The suggestion is that older participants encode words less effectively than the younger group, especially under free learning conditions. However, encoding is "repaired" for older individuals by the guidance provided by

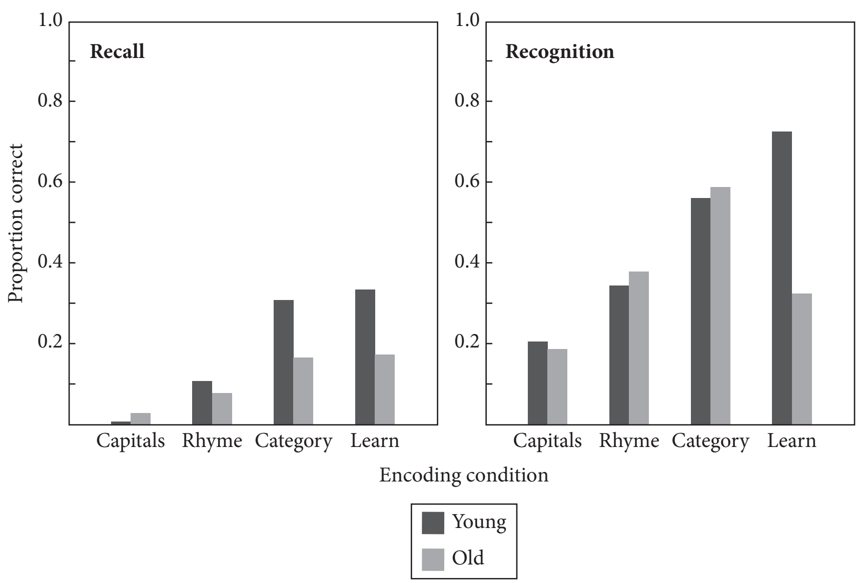

Fig. 7.2 Age-related differences in recall (left-hand panel) and recognition (right-hand panel) as a function of type of processing during encoding (Sharon White, reported by Craik, 1977a).

Reproduced from Birren & Schaie (Eds.), *Handbook of the psychology of aging* (pp. 384–420). NY: Van Nostrand Reinhold (1977) with permission from Elsevier.

the incidental encoding tasks but the age decrement in recall remains owing to less effective retrieval processes. In turn, this retrieval deficit is "repaired" by the use of a recognition test, which offers environmental support (see later in this chapter). So the combination of incidental encoding tasks and recognition testing equates performance of the two age groups (Figure 7.2, right panel) except in the case of free learning, where the initial age-related encoding deficit remains. A very similar result was found in a subsequent levels × aging study by Troyer, Häfliger, Cadieux, and Craik (2006). This pattern of data should *not* be taken to imply that age differences in memory do not "really" exist, however; rather, the age-related decrements stem from an inability to encode spontaneously in a deep, elaborate, and organized fashion, coupled with an inability to "self-initiate" adequate retrieval operations when processing is not well supported by the environmental context.

The 1977 chapter also pointed out similarities between the pattern of memory impairments associated with aging and those found in younger children and in patients with brain damage of various sorts. With regard to the child developmental literature, several researchers had postulated a "production deficiency" in children's learning abilities, such that younger children are able to use learning and recall strategies for remembering that are taught to them by others but are unable to formulate such strategies on their own (Flavell et al., 1966). In a sense, both younger children and older adults possess the neural machinery to carry out adequate encoding and retrieval operations but lack the control processes to initiate and run the machinery effectively. Speculatively, the control processes in question are mediated by the frontal lobes, which are known to develop slowly and are among the first brain areas to deteriorate in the course of aging (e.g., Diamond, 2002; Raz, 2000). The possible connection between healthy aging and frontal lobe dysfunction was examined directly in a study by Stuss et al. (1996). The results generally upheld the parallel between the effects of aging and the effects of frontal lobe damage in young adults.

Effects of aging: Loss of resources?

In the late 1970s and early 1980s I was greatly impressed by the similarities between the effects of aging and the effects of several other conditions on memory performance. In the free-recall paradigm, for example, age-related differences are minimal in recall of the last three or four words presented, but older adults recall fewer words from the first part of the list. Recall from terminal list positions ("the recency effect") is typically attributed to retrieval from PM as suggested previously, whereas recall of words from the beginning and middle of the list is attributed to retrieval from SM. The pattern of equivalent PM recall but impaired SM recall is shown by older adults relative to younger adults (Craik and Jennings, 1992), by intoxicated individual compared to sober individuals (Jones and Jones, 1977, by fatigued individuals (Craik and Simon, 1980), by participants encoding words under conditions of divided attention (DA) as opposed to under full attention (Craik and Byrd, 1982), and even by amnesic patients relative to control individuals (Baddeley and Warrington, 1970).

Are these similar patterns across very different cases attributable to some common cause? It is tempting to think so. Intoxication, fatigue, and DA are clearly all reversible conditions, whereas aging and amnesia are not; so at least the former group do not appear to reflect cases of structural damage. One factor that *is* common, in my opinion, is the reliance of recency recall on what Baddeley and Hitch (1974) termed the articulatory loop—the use of phonemic rehearsal to maintain the last few words in a free-recall list in mind before immediately recalling them. If this type of articulatory rehearsal is carried out by a relatively shallow or peripheral set of processes, they may be available to amnesic patients, as well as to older adults and to individuals who are intoxicated, fatigued, or are working under DA conditions. However, this similarity in immediate recall of recent items need not mean that deficits in SM are also due to the same mechanism across the different groups. One set of results that makes this point was reported by Cermak (1982). He had amnesic patients encode words semantically following the paradigm used by Craik and Tulving (1975) but found no improvement in retention. In this respect amnesic patients appear to be different from older adults and people encoding words under DA conditions, who show "repaired" levels of retention when semantic encoding is paired with a recognition test at the time of retrieval (Craik and Byrd, 1982; Troyer et al., 2006).

The finding that performing a concurrent task during memory encoding (DA) is associated with a reduction in later recall and recognition suggests that the reduction is attributable to a reduction in available processing resources. Quite simply, the concurrent task requires some of the attentional energy available to the person and this necessarily leaves less for the primary task. This notion was applied to aging by Craik and Byrd (1982); they suggested that some biological changes associated with the aging process have the effect of reducing the pool of available processing resources, with the result that the pattern of memory impairment shown by older adults resembles the pattern shown by younger adults working under conditions of DA—in some respects at least (but see Naveh-Benjamin, 2001).

It is also plausible that fatigue and non-optimal times of day (Hasher et al., 1999) are associated with a reduction in available processing resources. Given that alcohol has depressive effects pharmacologically it seems reasonable to suggest that a reduction in resources underlies the memory decrements in this case also. How might reduced resources affect memory? My theoretical perspective led me to suggest that a reduction in processing resources will reduce the level of processing or curtail the degree of elaboration of encoded items, and that these reductions in effective processing would then be reflected in poorer subsequent memory performance.

In support of this argument I present evidence in Chapter 9 showing that areas of the left ventral prefrontal cortex (PFC) are associated with semantic processing, and that activations in these areas are associated with high levels of memory performance. An obvious question is therefore whether levels of activation in this region are reduced in older adults relative to their younger counterparts. The answer appears to be yes: Studies by Roberto Cabeza and colleagues (Cabeza et al., 1997a) and by Cheryl Grady and colleagues (Grady et al., 1995; Grady et al., 1999) found age-related reductions in left PFC activation, and that these reductions are matched by age-related reductions in memory for the material processed in the scanner. One interesting twist to the results of Grady et al. (1999) was that when stimuli were presented as pictures of objects rather than as the object's name, there were no differences in the levels of left prefrontal activation between younger and older participants, and also no age-related differences in the levels of subsequent recognition memory. The possibility that pictures can "repair" the encoding inefficiencies of older adults is discussed later in this chapter.

It now seems clear that a region of the left inferior PFC is involved in the processing of meaning (Kapur et al., 1994; Petersen et al., 1988) and that the level of activity in this region drops from semantic processing to phonemic processing (Kapur et al., 1994), from younger adults to older adults (Cabeza et al., 1997a; Grady et al., 1995), and from processing under full attention to processing under DA (Shallice et al., 1994). The implication with regard to aging is therefore that older adults do not process material so richly and meaningfully as younger adults do, and that this processing inefficiency results in a reduction in subsequent memory performance. The similar result involving DA suggests that available processing resources are reduced in older adults, just as they can be temporarily reduced in younger people when they perform a concurrent task along with memory encoding.

But what exactly are these "processing resources" that decline with age? The answer is still obscure. It makes sense to me that the amount of cortical activity that can take place at any one time should reduce as the brain becomes less efficient with age, but the empirical evidence on this point is still lacking. The phenomenon of "repaired processing" as a function of greater amounts of environmental support is an interesting one. Just as with production deficiency in children, it seems that the provision of "good" semantic processing at encoding can be complemented by providing more external cues to support retrieval,and that provision of the item itself in the form of a recognition test is particularly helpful. Some studies describing this effect will be described shortly, but for the moment I will illustrate the idea by presenting the results of Grady et al. (1999). These authors presented stimuli either as names (words) or as line drawings (pictures) of objects under three encoding conditions: Shallow processing (questions about the size of picture or case of letters), deep processing (Is the object living or non-living?), or intentional learning (learn these items for a later memory test); the shallow and deep conditions made no mention of a memory test. The encoding phase was carried out in a positron emission tomography (PET) scanner by groups of 12 younger and 12 older adults. Following the scans, participants were given a recognition test in which the stimuli were all words, regardless of encoding conditions. Table 7.1 shows recognition performance levels for both age groups, two types of material, and encoding conditions.

Analyses of these behavioral data found main effects of material (pictures better than words), of age (young better than old), and encoding condition (learn > deep > shallow). Subsequent analyses within each material type showed a significant effect of age for word stimuli but not for pictures. That is, presentation of the names as pictures of objects "repaired" encoding in the older group to the point that their memory performance levels were equivalent to those of young adults (see Craik and Schloerscheidt, 2011, to be described later, for a similar result). The PET results of interest in the present context include activations in left frontotemporal regions that were significantly smaller for older participants when processing words. In the case of picture stimuli, however, activation in the left inferior PFC was again greater in the deep and intentional learning conditions than in the shallow condition, and this pattern of activation did not differ between the two age groups. It seems then that deeper processing of picture stimuli resulted in equivalent levels of activation in left prefrontal regions and also in equivalent levels of recognition memory.

So one line of argument is that aging is associated with a reduction in available processing resources (as in the case of DA and possibly other conditions) and that this reduction results in processing that is less deep and elaborate, leading, in turn, to reduced levels of subsequent recollection. However, this age-related processing inefficiency can be repaired by the provision of greater environmental support in the form of picture stimuli in the case of the Grady et al. (1999) study. It does not seem reasonable to suggest that pictures somehow provide more resources, however, and I have argued in previous publications that pictures provide more support

Table 7.1 Percentages of hits minus false alarms for picture and word recognition as a function of age group and type of processing during encoding (Grady et al., 1999).

Materials:	**Pictures**		**Words**	
Age groups:	**Young**	**Old**	**Young**	**Old**
Encoding condition				
Shallow	49	41	28	9
Deep	57	55	55	40
Learn	68	64	58	42

Source data from Grady CL, McIntosh AR, Rajah MN, Beig S, Craik FIM. The effects of age on the neural correlates of episodic encoding. Cereb Cortex. 1999 Dec;9(8):805-14. doi: 10.1093/cercor/9.8.805.

to appropriate encoding activities, much as the provision of a cane or a walker can assist effective movement, or alternatively much as provision of a written text or sheet music can support the performance of a partly learned speech or musical performance. The idea of environmental support is spelled out more fully in a later section.

Effects of aging: Loss of cognitive control?

Most machines require both a source of power to run their mechanisms and also guidance systems to coordinate their components and steer their output appropriately. The brain is essentially a large and complex machine, so it too requires control functions and energizing resources that may speculatively include arousal level and patterns of neural network activation. In turn, these functional changes must ultimately depend on such biological factors as cerebral blood flow and glucose metabolism. In the previous section I presented some ideas and findings in line with the proposal that available neural resources ("mental energy") decline in the course of aging. Other researchers have suggested that an age-related impairment in cognitive control is a preferable description, and this makes sense to me, although I believe that *both* constructs of resources and control are necessary.

Lynn Hasher and Rose Zacks have made formidable contributions to our understanding of cognitive aging, and have been leaders in the theoretical camp promoting and illustrating the notion that controlled processing declines in effectiveness over the adult years, whereas automatic processing remains relatively stable. Hasher and Zacks (1979) proposed a framework that integrates resource and control concepts by suggesting that *automatic processes* occur without intention, do not benefit from practice, and require minimal amounts of attentional energy. Many such processes may be genetically "wired in" and others are developed as a result of extended practice, and function to prevent the components of skilled behavior overloading the limited-capacity attentional system. However, such *effortful processes* as rehearsal, elaboration, and retrieval are typically intentional, require resources and do benefit from practice. With regard to aging, Hasher and Zacks propose that automatic processes are relatively immune to the effects of aging but that effortful processes decline in effectiveness over the adult lifespan. In subsequent articles (Hasher and Zacks, 1988; Hasher et al., 1999) they emphasize the notion of inhibitory control in working memory, and that control processes perform the essential functions of access, deletion, and restraint over prepotent response tendencies. From their perspective, "control is the degree to which an activated goal determines the contents of consciousness" (Hasher et al., 1999, p. 653). In the present context one other major conclusion is that inhibitory control declines in the course of aging, and that this declining efficiency underlies many age-related decrements in memory, attention, learning, and thinking.

Larry Jacoby and his colleagues (Hay and Jacoby, 1999; Jennings and Jacoby, 1993, 1997) developed a similar line although from a somewhat different perspective. They used Jacoby's (1991) "process dissociation procedure" (PDP) to separate the direct, consciously controlled component of *recollection* from the indirect, implicit component of *familiarity* in recognition memory tests. In one such study (Jennings and Jacoby, 1993) they compared the performance of groups of older and younger participants on a fame judgment task in which participants first read a list of fictitious ("non-famous") names. They were then given two successive tests of fame recognition, consisting of a long list with some real famous names intermingled with the non-famous names from the first phase and some new non-famous names. In the first test participants were misinformed that names from the initial study phase were actually names of famous people, so should be included in their "famous" responses. In the second test they were now correctly informed that the initial names were *not* famous, so should be excluded. Contrasts of responses from these inclusion and exclusion tests yielded estimates of conscious recollection and automatic familiarity (see Jacoby, 1991, for details). The experiment also included a second group of young adults who performed the initial study phase while performing a second unrelated task—that is, under conditions of DA. The clear-cut results showed that estimates of recollection for the young–full attention, young–divided attention, and elderly groups were 0.60, 0.34, and 0.31, respectively; performance by the first group was significantly higher than estimates for the other two groups, which did not differ. In contrast to these measures of recollection, estimates of familiarity were 0.33, 0.38, and 0.39 for the three groups, respectively; these estimates were all statistically equivalent. Thus, the experiment nicely shows no differences due to age or DA in the automatic component, but marked (and comparable) reductions in recollection associated with aging and division of attention in the consciously controlled recollection component.

In an interesting follow-up study with older adults Multhaup (1995) failed to find the "false fame effect" with repeated non-famous names, but in her study the older participants were explicitly asked whether each test name was famous, non-famous, or one they had read earlier. Jennings and Jacoby agree that increasing the structure or retrieval support by directly asking about the source of each name diminishes the effect but suggest that the problem for older people is "an inability to monitor in unstructured situations" (Jennings and Jacoby, 1997, p. 360). It is worth noting that recollection, as measured by the PDP analysis, essentially relies on the person's ability to retrieve the source or context of previous occurrence. Schacter and colleagues made the point some years ago that damage to the frontal lobes results in a failure to remember source information (Schacter et al., 1984). Given the likelihood that normal aging is associated with inefficient frontal function (see Stuss and Knight, 2002), and the finding that older adults have problems in remembering the source of information (McIntyre & Craik, 1987), Jacoby's results using PDP fit the known facts nicely and add complementary information to a growing consensus.

Some further points from Jacoby's perspective were noted by Hay and Jacoby (1999). They found that older adults were impaired in a facilitation condition, as well as in a condition involving inhibition. The implication is that the failure of older adults to profit from the facilitating circumstances strongly suggests an age-related impairment of general *control*, rather than an impairment of inhibitory processes only (as emphasized by Hasher et al., 1999) or a reduction in processing resources (as emphasized by Craik and Byrd, 1982). Hay and Jacoby also comment that in order to improve performance, an "inhibition" account suggests that the inhibitory powers of older adults should be strengthened by special training in order to suppress interference, whereas the PDP approach suggests that memory should be improved by bringing in more information to enhance recollection. The general conclusion that recollection declines with age but familiarity does not is now well accepted, however. Koen and Yonelinas (2016) reported converging evidence to this effect from several different measures. In a previous article Koen and Yonelinas (2014) showed that recollection depends on processing in the hippocampus, whereas familiarity reflects processing in the perirhinal cortex.

The conclusion that aging is associated with a decline in recollection—the ability to reinstate aspects of initial occurrence and aspects of the person, object, or event not provided by the current percept—but that familiarity remains stable across the adult lifespan is, of course, very much in line with Hasher and Zack's (1979) proposal that controlled processes decline but automatic processes are maintained in the course of aging. How exactly controlled processing works is still very much a matter of debate, however. One further important body of work on the topic of controlled processing in aging has been carried out by Braver, Barch, and their colleagues (Braver and Barch, 2002; Braver et al., 2001). They proposed a *goal maintenance account* of working memory, which suggests that current goals are maintained in working memory, and that this task-appropriate set influences the selection of relevant cognitive processing regions and the flow of information among them. With regard to aging, Braver and colleagues propose that the ability to maintain an effective task set declines across the lifespan (Braver and West, 2008).

One study from my laboratory yielded a more positive spin to the debate on age-related changes in cognitive control. The study was led by Alan Castel, then my graduate student and now a Professor of Psychology at UCLA. We used an ingenious short-term recall paradigm devised by Michael Watkins and Lance Bloom, and reported by them in 1999 in an unpublished paper. Participants are presented with 12 words for immediate free recall, and each word is assigned an arbitrary value from 1 to 12 such that each value is used once, distributed randomly through the list. Words are presented visually along with the word's value; for example, a list might start TABLE—6, PIZZA—10 and so on. The participant's task is to maximize the value of recalled words, so their 'score' for each list will be greater to the extent that they hold high-value words in working memory and recall them first. In the study reported by Castel et al. (2002), we presented 48 such lists at a 1-second rate to groups of younger and older adults, with feedback on performance given after each recall attempt.

The results (Figure 7.3) showed that both age groups were sensitive to the value manipulation—values of Spearman's rank order correlation rho (recall probability as a function of value) were 0.97 for younger adults and 0.99 for older adults. Strikingly, the older group's performance levels were at least as high as their younger counterparts' for the high-value words, although they retrieved fewer words from those valued at 9 or less. It seems that in this particular task older adults can select and hold high-value items in working memory as efficiently as can younger adults, thereby demonstrating excellent cognitive control. Speculatively, this apparent anomaly may be due to the point that "control" in the present case is strongly supported by the perceptual environment (the values are shown explicitly with each word and can be maintained by conscious rehearsal) as opposed to other cases involving control over deeper cognitive operations. In the same vein, it is worth noting that the pattern shown in Figure 7.3 is essentially identical to the pattern found for age differences in free recall of word lists when the *x*-axis is serial position. As described earlier, there are substantial age-related decrements in early serial positions where recall is attributed to secondary memory retrieval, but none

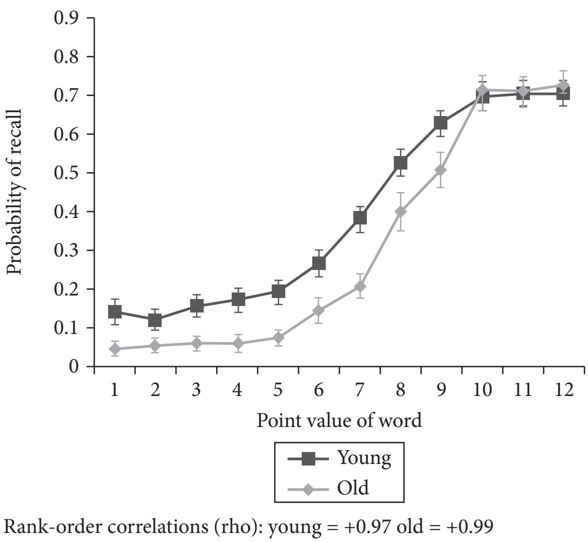

Fig. 7.3. Recall probability as a function of age and point value (Castel et al., 2002, Experiment, 1).

Source data from Castel AD, Benjamin AS, Craik FIM, Watkins MJ. The effects of aging on selectivity and control in short-term recall. *Mem Cognit.* 2002 Oct;30(7):1078-85. Doi: 10.3758/bf03194325.

in the last few serial positions (the recency effect), attributed to recall from primary memory. Age differences are minimal for the 2–4 items held "in mind"—either because they have just been perceived or because they have been selected and maintained until a response is required.

Environmental support and self-initiated activities

I spent the academic year 1982–83 at the Center for Advanced Study in the Behavioral Sciences, associated with Stanford University. Each year the Center takes in a different cohort of Fellows from disciplines across social and behavioral sciences, provides a pleasant, if simple, woody study overlooking the Stanford campus, also lunch and occasional social occasions—and otherwise leaves the Fellows to mingle, tangle, and wrangle without let or hindrance! The Center thus provides an excellent setting to work without deadline pressures, without tedious committee meetings, and with the opportunity to discuss ideas with a group of very bright people. The late great Amos Tversky dubbed it "the leisure of the theory classes"!

In my case I was lucky that the Class of 82–83 included a number of colleagues interested in memory theory. The group included Robert Crowder, Matthew Erdelyi, Roberta Klatzky, and Tom Trabasso, and we met weekly to discuss issues of mutual interest. I found our conversations to be stimulating and often provocative as my colleagues approached our common problems from different angles. These discussions led me to consolidate my own overall view, with age-related impairments regarded as inefficiencies of processing attributable ultimately to an age-related decrease in available processing resources. These processing inefficiencies could be repaired, however, by coupling a semantic orienting task at encoding with a supportive recognition test at retrieval, as demonstrated in studies reported by Craik (1977a) and by Craik and Byrd (1982). This line of thought also reinforced the parallel between remembering and perceiving, and the idea that just as perceiving necessarily involves the interaction between externally provided stimuli and internally generated processes of interpretation, so remembering involves the interaction between externally provided questions, cues and relevant context with internally generated reinstatement of encoded past events and information. In more general terms, remembering involves transactions between information provided by the current environment ("environmental support") and processes generated by the person ("self-initiated activity").

In the case of aging, if self-initiated retrieval activities are less efficient, the older person will require a stronger boost from environmental support to achieve the same level of performance as a younger person. Further, different types of memory task may be regarded as involving different amounts of environmental support. For example, free recall involves little support; the person is simply instructed to recall the recently presented list of words, and the same description applies to a person attempting to recall a series of events that happened in very different surroundings. These tasks rely heavily on self-initiated activities, and as such are often poorly performed by older adults. Environmental support can be added, however, in the form of cues, contextual reinstatement, or even reinstatement of the wanted information itself in the case of recognition memory. If this analysis is correct, then older adults should profit differentially from the provision of more environmental support, and this is exactly what the evidence shows (Craik, 1977a; Craik and Byrd, 1982; Craik and McDowd, 1987; Troyer et al., 2006).

While I was at the Stanford Center, Donald Broadbent organized a meeting at the Royal Society in London on functional aspects of human memory, and I was invited to present a paper. Broadbent asked me to address the topic of "transfer of information from temporary to permanent memory"—presumably the notion that was central to Atkinson and Shiffrin's (1968) proposal that information is held first in a temporary short-term store and is then transferred by rehearsal or other means to a more permanent long-term store. I gratefully accepted the invitation (who could resist the opportunity to address the Royal Society of London after all?!) but (rather *un*gratefully I suppose) argued in the paper and subsequent article (Craik, 1983) that the concept of "transfer" was unnecessary. Nothing is "transferred" from short-term memory to long-term memory, in my view; more simply, information is encoded in memory as a function of the type of processing carried out during the encoding phase (Craik and Lockhart, 1972) augmented by processing carried out during subsequent rehearsal or further study phases. In the 1983 article I also brought in my more current notions of environmental support and self-initiated activity, and illustrated them with a scheme similar to the one shown in Figure 7.4 (reproduced for convenience from Figure 5.1).

The proposal that age-related differences in memory performance are substantial in free recall, less in recognition memory, and even less in repetition priming (a form of procedural memory) was later validated and confirmed in a meta-analysis reported by La Voie and Light (1994). As an index of differences in performance levels between younger and older groups of adults, they reported values of Cohen's *d* to be 0.97 for recall, 0.50 for recognition, and 0.30 for priming. One point to add here is that it seems likely that self-initiated activities are mediated by processes in the frontal lobes, and that age-related declines in frontal lobe efficiency underlie the age-related decline in self-initiated abilities and the complementary necessity to rely on greater amounts of environmental support. The argument, with some empirical illustrations, was continued in a subsequent paper presented at a meeting in East Berlin to celebrate the centenary of Hermann Ebbinghaus (Craik, 1986).

These ideas are also relevant to notions of cognitive control. It may be argued that adaptive behavior in simple animals is controlled very substantially by environmental inputs and by events interacting with genetically preprogrammed stimulus-response tendencies, and that behavior relies on environmental

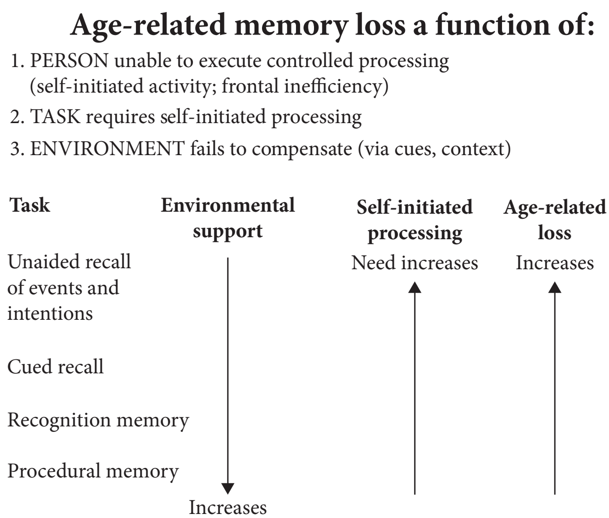

Fig. 7.4 Age-related memory losses as a function of different tasks (see text).
Source data from Craik F. I. M. (1983) On the transfer of information from temporary to permanent memory. *Phil. Trans. R. Soc. Lond.* B, 302, 341–359. http://doi.org/10.1098/rstb.1983.0059.

regularities and constancies to maintain an adaptive balance. Such dependence may be illustrated by experiments in which the environment is altered in some relevant way. I remember hearing in a biology class about a rather heartless study involving a species of tiny crabs that forage at low tide on various Pacific shores. As the tide returns, the rising water triggers a wired-in impulse for them to scuttle eastwards and to safety. The unfeeling experimenters transported them to the *east* coast of America, however, and now sadly the turning tide impelled them to scuttle hopelessly ever deeper into the depths of the Atlantic Ocean.

As animals evolved, however, the external environment came to be represented *within* the brain, and could now be manipulated by internal control processes, speculatively mediated by functional networks in the frontal lobes. Control could thus now be detached from the inbuilt or learned dependence on external stimulation if circumstances warranted the change. The proposal that control under the rubric of self-initiated activities is mediated substantially by the frontal lobes is supported by clinical observation that patients with frontal lobe damage exhibit "utilization behavior" in which they carry out actions inappropriately driven by the associations to objects placed in front of them (Lhermitte et al., 1986). In the case of mild frontal inefficiency associated with healthy aging, this tendency may be manifest by a greater reliance on habitual modes of responding and a decreased ability to tailor responses to the specific demands of particular circumstances. This reversion to habit-driven responding in older adults and in younger adults whose attention is divided is nicely illustrated in a series of studies from Larry Jacoby's laboratory (Hay and Jacoby, 1996, 1999; Jennings & Jacoby, 1993).

I have emphasized age-related difficulties in self-initiation at retrieval and in constructing adequately deep and elaborate representations at encoding, both of which implicate deficits in cognitive control and therefore in frontal lobe functions. Clearly, other age-related deficits in brain functioning exist, however (see Raz, 2000; Moscovitch and Winocur, 1992), including impairments of medial-temporal operations (Dennis and Cabeza, 2008). Moshe Naveh-Benjamin has highlighted a specific deficit in associative processing in older adults and shown that whereas older participants show a disproportionate loss in associative information compared to memory for items, younger adults working under conditions of DA show equivalent deficits for item and associative information (Naveh-Benjamin, 2001). We subsequently replicated these observations in my own laboratory (Craik et al., 2010). This discovery led to some informal suggestions that I presented to the Annual Meeting of the APA in Toronto in 2000. The main point was to suggest a two-factor model of age-related memory loss, with one factor stemming from frontal inefficiencies and the second factor related to age-related losses in hippocampal and medial-temporal functioning. The frontal factor was characterized as underlying reduced control in older adults and is mimicked by DA in young adults. In contrast, the medial-temporal factor is apparently *not* mimicked by DA, but does underlie such deficits as loss of associative information and age-related loss of "source" information (McIntyre and Craik, 1987; Naveh-Benjamin, 2000).

8

Aging II

Later Empirical Work

With regard to age-related changes in memory performance, the points to illustrate from my perspective in the 1980s and beyond include the idea that age-related impairments do not reflect some structural change in memory stores or memory systems, but rather reflect a progressive inability to carry out certain processing operations. Such operations include self-initiated retrieval processes and the ability to recollect the original context in which an event occurred. In turn, these inefficiencies are attributed to a decline in available processing resources and the declining effectiveness of executive control processes. I next describe some studies that addressed these points.

Some empirical illustrations

Schonfield and Robertson (1966) showed that whereas older adults performed poorly on recall tasks relative to their younger counterparts, age-related differences in recognition memory were comparatively slight. This result fits an account in terms of the greater need for self-initiated activities in recall, but an alternative possibility is that recall is simply more difficult than recognition, and that age-related decrements may be amplified by task difficulty. In a study carried out with my graduate student Joan McDowd and reported in Craik (1986) we addressed this problem by constructing easy and difficult versions of free recall tasks and also of recognition tasks. If the interaction between age and recall/recognition is still found regardless of difficulty level, the result could be attributed more clearly to the tasks themselves rather than to difficulty. In outline, the easy recall task involved free recall of an eight-word list; the difficult version involved a 14-word list. The relatively easy recognition task used untested words from eight-word lists in a yes/no recognition test with a 2:1 distracter-to-target ratio. The difficult recognition task used untested 14-word lists in a yes/no test with a 5:1 distracter-to-target ratio. The data revealed an age × task interaction but no age × difficulty interaction. In the young adult group, a comparison of the easy recall test and the difficult recognition test showed that recall gave a higher performance level than recognition (means of 0.55 and 0.48, respectively). However, the corresponding means for the older adults were 0.28 and 0.39, respectively; that is, the age-related decrements

Remembering. Fergus I. M. Craik, Oxford University Press. © Oxford University Press 2021.
DOI: 10.1093/oso/9780192895226.003.0008

were 0.27 for recall and 0.09 for recognition, even though recall was now "easier" than recognition—in terms of performance levels at least.

McDowd and I carried out a second experiment to explore the ideas that recall demands more self-initiation than does recognition, and that resource-demanding tasks such as recall are associated with greater costs to older adults (Craik and McDowd, 1987). We attempted to equate the difficulty levels of recall and recognition by presenting compatible cue–target pairs (e.g., "part of a tree—TWIG") auditorily for a later spoken cued-recall test ("part of a tree --?"). Lists of 12 cue–target pairs were presented and tested at the end of each list. Other cue–target lists were not tested immediately; in these cases, the target words were mixed with the same number of new words, and presented as a recognition test following completion of all the presentation and recall tests. Participants also performed a visually presented secondary task during the spoken recall and recognition retrieval tests. This task consisted of a visual display of one of four types of stimulus: A consonant, a vowel, an even digit, or an odd digit. There were four corresponding response keys, and the task was to press the key associated with the current stimulus type. Pressing the correct key caused the next stimulus to appear immediately, so the task was a continuous reaction time (CRT) task with performance measured by the speed of responding. After practice, the secondary task was performed on its own to provide a baseline measure for each participant; during the main experiment the CRT task was performed concurrently with the recall and recognition tests.

The results are shown in Figure 8.1. The left-hand panel shows recall and recognition performance, and it may be seen that older adults show an age-related decrement in recall but not in recognition. The age × task interaction was again significant despite the point that recall is now the "easier" task, in terms of performance level at least. The right-hand panel shows RT *costs*—that is, the mean extra time above each participant's own RT baseline it took to make a correct CRT decision when the CRT and retrieval tasks were performed concurrently. Statistical analyses found a main effect of task (recall was more resource-demanding than recognition), a main effect of age (costs were greater for older adults), and an age × task interaction showing that costs were particularly large for older adults performing the cued-recall test. We concluded that recall tasks are more resource-demanding than recognition tasks (see Figure 8.1) and that older people have a smaller pool of processing resources on which to draw.

Some further studies (e.g., Baddeley, 1996; Greene et al., 1996) did not replicate the finding that older adults are relatively more impaired on recall tests than on recognition tests so, in order to address differences between the studies, Danckert and Craik (2013) ran three experiments whose results confirmed the Craik and McDowd findings. At this point I feel comfortable with the various claims that recall demands more "self-initiation" than does recognition memory, older adults have fewer attentional resources than younger adults, and that older adults

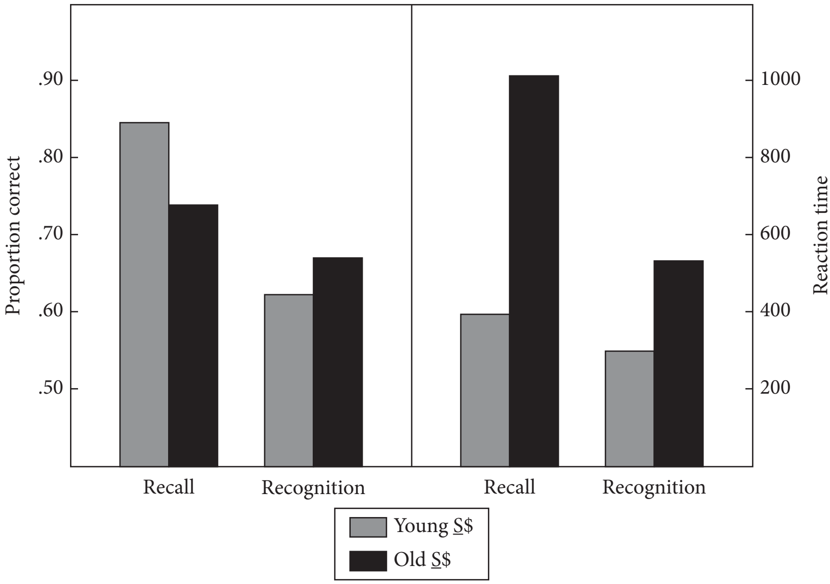

Fig. 8.1 Left-hand panel; cued recall scores and recognition memory as a function of age. Right-hand panel; reaction time costs (msec) for recall and recognition as a function of age .

Reproduced from Craik, F. I. M., & McDowd, J. M. (1987). Age differences in recall and recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 13(3), 474–479. https://doi.org/10.1037/0278-7393.13.3.474 with permission from APA.

therefore show greater age-related decrements on recall than on recognition tests (but see Benjamin, 2010, for an alternative account).

I have subsequently been involved in experiments that add further weight to the conclusions that recall processes are particularly resource-demanding in older adults and that age-related decrements can be "repaired" by providing greater amounts of environmental support. One large study was carried out in collaboration with Moshe Naveh-Benjamin and other colleagues (Naveh-Benjamin et al., 2005). My friend Moshe loves a bit of complexity in his experiments, and this one had essentially five factors—age, meaningfulness of materials, the use of strategies, division of attention (DA), and the *location* of DA—at encoding or retrieval. The study explored several questions. One was the extent to which either teaching a mnemonic strategy or using more meaningful materials might differentially benefit older adults. The chosen paradigm was paired-associate learning using auditorily-presented word pairs that were either completely unrelated or were somewhat related so that participants could form a meaningful connection between them. A second manipulation, necessarily carried out on different groups of younger and older adults, was to ask one group at each age level simply to learn the word pairs as best they could, and to teach the other half of participants at each age level such strategies as imagery, elaboration, and story production. One idea here was that the increased relatedness should provide a benefit "automatically"—it is given in the material—whereas the use of strategies is more deliberate, effortful, and apparently resource-demanding. We predicted that the older participants would thus show a benefit from increased relatedness but perhaps not (or at least less) from strategy teaching. The manipulations of DA was thrown into the mix to obtain further information on the different negative effects of DA at encoding (substantial) and retrieval (surprisingly slight; see, e.g., Craik et al., 1996), and information on interactions with aging in these respects. Given that my senses begin to spin when contemplating any study with more than *three* variables, Moshe kindly consented to run the location of DA (encoding or retrieval) as two separate experiments. So, each of the two experiments ended up with four factors: Age group, full versus DA, relatedness of word pairs, and strategy teaching. Relatedness and DA were run as within-subject variables, whereas age and strategy were between-group variables.

The concurrent task was a visual tracking task in which a green asterisk moved continuously around a computer screen at a smooth rate of 6 cm/second in an unpredictable fashion. A white dot was also visible on the screen, and its movements were controlled by a computer mouse manipulated by the participant. The task was to track the moving green asterisk by keeping the white dot as close as possible to it. Deviations between the dot and the asterisk were measured continuously by a computer program; the logic was that close attention was required to track the asterisk effectively and that greater deviations measured the amount of attention used by memory encoding or retrieval processes. Both the encoding and retrieval intervals were 6000 msec. The tracking task was performed under full attention (FA) to obtain a measure of baseline performance for each participant individually, and the difference in tracking deviations between baseline and dual-task performance yielded a measure of concurrent task costs for each participant throughout the 6-second encoding and retrieval intervals.

The main memory results from Experiment 1 (DA at encoding) are shown in Figure 8.2 and are surprisingly straightforward. There is a main effect of relatedness—data points in the left half of the figure are generally higher than those on the right. There are also main effects of aging (young > old), of strategy (strategy > no strategy), and of attention (full > divided). Additionally, age group interacted with relatedness (old adults showed greater benefits than younger adults) but not with strategy; in this latter case the two groups benefited equally from strategy instructions. These interaction results were somewhat surprising in that relatedness had been considered relatively automatic in the support it provided and was therefore expected to benefit the two age groups equally, whereas strategy required self-initiation, and was expected to be of greater benefit to younger adults. In the article, we concluded that relatedness was a form of "schematic support" that is used spontaneously by younger adults (i.e., they can construct meaningfulness even from

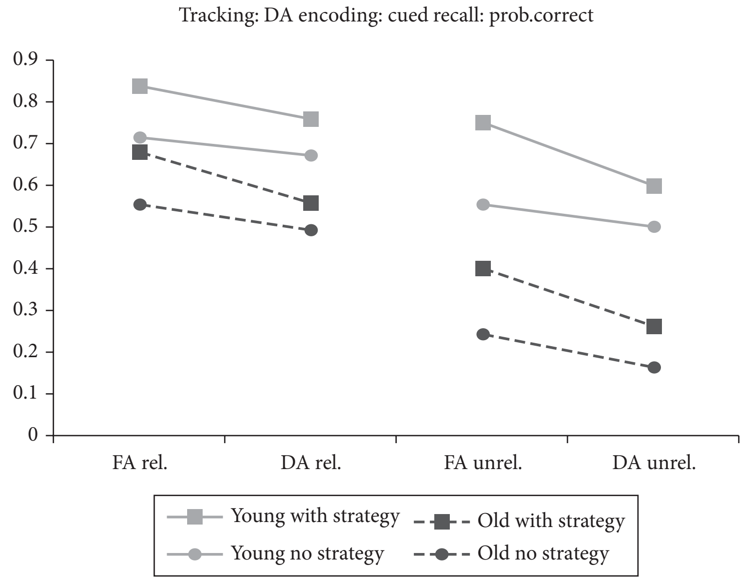

Fig. 8.2 Proportions of words recalled as a function of age, strategy, division of attention at encoding and relatedness. FA = full attention; DA = divided attention; Rel. = related; Unrel. = unrelated pairs (Naveh-Benjamin et al., 2005, Experiment 1).
Reproduced from Naveh-Benjamin, M., Craik, F. I. M., Guez, J., & Kreuger, S. (2005). Divided Attention in Younger and Older Adults: Effects of Strategy and Relatedness on Memory Performance and Secondary Task Costs. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 31(3), 520–537. https://doi.org/10.1037/0278-7393.31.3.520 with permission from APA.

nominally "unrelated" pairs) but not by older adults; the provision of meaningful pairs thus helps older adults more, much as older adults benefit disproportionately from a recognition test compared with a recall test.

With regard to strategy, although the two groups showed equal benefits, the use of strategy was associated with a significant increase in concurrent task costs for older adults but not for younger adults. So, older individuals profited from the use of effortful strategies but at some cost of attentional resources. Finally, there was no age × DA interaction in Experiment 1, although this interaction was reliable in Experiment 2 in which attention was divided at retrieval; the older adults were more penalized by the DA condition.

Concurrent task costs are also of interest. Figure 8.3 shows CRT *costs*—that is, greater deviations between the chaser dot and the target asterisk than was found for each participant when doing the tracking task alone ("baseline"). The figure summarizes CRT costs for both age groups in the two experiments; thus, costs are shown across the 6-second interval used for both encoding and retrieval and for both younger and older adults. In the case of younger adults, they are able to maintain visual tracking performance while performing the auditory/spoken encoding

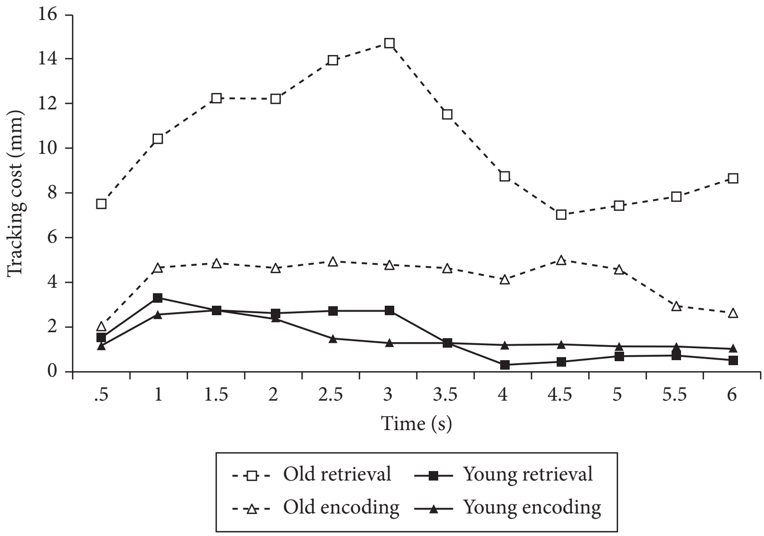

Fig. 8.3 Tracking task costs (mm) as a function of age and locus of the DA task (at encoding or retrieval). The *x*-axis represents the 6000-msec interval to encode or retrieve each item .

Reproduced from Naveh-Benjamin, M., Craik, F. I. M., Guez, J., & Kreuger, S. (2005). Divided Attention in Younger and Older Adults: Effects of Strategy and Relatedness on Memory Performance and Secondary Task Costs. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 31(3), 520–537. https://doi.org/10.1037/0278-7393.31.3.520 with permission from APA.

and retrieval tasks at almost the same level as while performing the tracking task alone; that is, concurrent task costs are minimal for them during both encoding and retrieval. The pattern of costs is very different for older adults, however. Tracking behavior is less efficient during encoding than it was during baseline (tracking alone) trials, and these attentional costs last throughout the 6-second encoding interval. During retrieval, costs for the older participants are substantial, and seem to peak at around 3 seconds after the cue word was presented—possibly due to the successful retrieval of at least some words. In summary, concurrent task costs are greater for older than younger participants, especially during the retrieval phase.

The notion that inefficient encoding processes in older adults can be repaired by the provision of greater support has been illustrated in different ways in various experiments. Encoding can be supported by inducing semantic processing by means of orienting tasks, and when such enhanced encoding is paired with a supportive recognition task at retrieval we have seen that age differences in memory can be reduced and even eliminated (e.g., Craik, 1977a; Craik and Byrd, 1982; Troyer et al., 2006). A further method to induce a richer encoding is to present stimuli as pictures rather than words. The idea here is that pictorial stimuli (either of scenes or pictured objects) "drive" a rich semantic representation of the pictured material relatively automatically, compared to words that may simply evoke a lexical representation unless paired with a semantic orienting task. The comparative age-related difference in performance between recall following word presentation on the one hand and recognition following picture presentation was illustrated by an unpublished experiment carried out by Jan Rabinowitz, Brian Ackerman, and myself but reported by Craik and Byrd (1982). In essence, free recall performance following word presentation was 0.33 for young adults and 0.17 for older adults. When the same participants learned lists presented as line drawings of objects, however, and memory was tested by recognition, the scores were now 0.84 for young adults and 0.83 for older adults (see Table 3.2). The combination of rich encoding conditions and supported retrieval conditions eliminated the age difference.

The same point was made by a more complex experiment carried out in collaboration with Astrid Schloerscheidt (Craik and Schloerscheidt, 2011). In this study, stimuli to be remembered were names of common objects for half of the participants (Experiment 1A) and photographs of the same objects for the other half (Experiment 1B). In both cases each stimulus was presented paired with one of 10 background scenes—colored photographs of city scenes and landscapes—with the instruction to try to make a connection between the item and its accompanying scene, and to remember the pairing for a later memory test. In the subsequent test, items were again paired with scenes, and the accompanying scene could either be the *original* scene used at encoding for that item, a *switched* scene (i.e., one used at encoding but with different items), *no scene*, or a completely *new* scene that had not been used in the encoding phase. The point was to manipulate the similarity of encoding/retrieval context, with the prediction that the age-related decrement would be least with pictured items and with reinstatement of the original context. Experiment 1A (words) involved groups of 25 younger and older adults and Experiment 1B (pictures) tested groups of 32 younger and older adults.

The results are shown in Figure 8.4. For word stimuli (left-hand panel) reinstatement of the *original* scene context led to the highest performance for both age groups. The conditions *switched*, *none*, and *new* were associated with a lower but stable level of performance for the younger participants, but with progressively lower levels of performance for the older group. An analysis of variance (ANOVA) on these data yielded significant effects of age and context, as well as a marginally significant interaction ($p = 0.08$) between the two variables. For picture stimuli the pattern is radically different; now older participants scored at least as highly as their younger counterparts and the context manipulation had a smaller effect. An ANOVA combining the two parts of the study showed significantly higher recognition performance for pictures than for words, and that this material advantage interacted with both age and context. The interaction with age confirms the prediction that older adults would benefit more from picture presentation; the interaction with context shows that context effects were greater for words than for pictures.

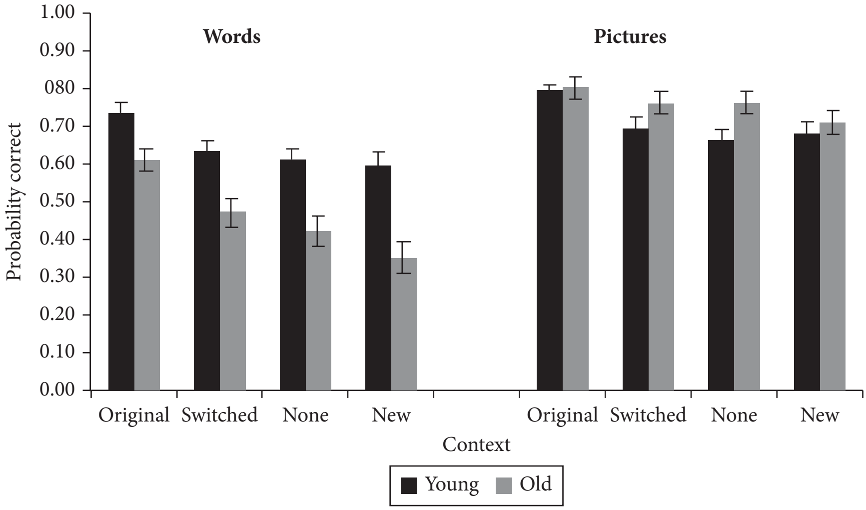

Fig. 8.4 Recognition memory for words (names) and pictures (photographs) as a function of age and context.

Reproduced from Craik, F. I. M., & Schloerscheidt, A. M. (2011). Age-related differences in recognition memory: Effects of materials and context change. *Psychology and Aging*, 26(3), 671–677. https://doi.org/10.1037/a0022203 with permission from APA.

It may be said speculatively that context reinstatement plays a bigger role with weaker stimuli and with individuals who encode less robustly. Finally, the three-way interaction among age, picture/word, and context was also significant. For word materials, context effects were larger for older adults, whereas for pictures, context had a slightly greater effect on young adults.

Age-related differences in working memory

When Mary Gick and Robin Morris worked in my laboratory as postdocs in the late 1980s we carried out a series of studies on age-related differences in working memory (WM). Robin's PhD was supervised, in part, by Alan Baddeley, so he brought the latest hot news from Cambridge to Toronto! Robin's major interests are in the neuropsychology of memory and executive functioning; after returning to the UK he was a faculty member and clinical researcher at King's College London and the Institute of Psychiatry before retiring in 2018. Mary Gick is now also retired; she was a faculty member in the Department of Psychology at Carleton University, and her later research interests were in Health Psychology. Together we published several articles on age differences, summarized in a chapter by Craik, Morris, and Gick (1990a) in a book, *Neuropsychological Impairments of Short-term*

Memory, edited by Giuseppe Vallar and Tim Shallice. The main findings were that age-related differences in primary memory were minimal but that age differences in WM were substantial, and were magnified by the increasing complexity of operations carried out in the WM task. This distinction between primary and working memory clarifies the earlier conclusion of Welford (1958) that age-related deficits in "STM" (short-term memory) underlie deficits in many higher-order cognitive functions. We also concluded that it is not a difficulty of "storage" that gives older people problems in short-term processing situations, but rather an age-related decrease in the flexibility and computational abilities of the central processor.

This primary/working memory distinction was also illustrated by a study carried out by Mary Gick and myself, and reported by Craik (1986). We contrasted word span with "alpha span" performance in younger and older adults. In alpha span (reported more fully by Craik et al., 2018a) participants are given a short list of words and must say them back in correct *alphabetical order*. So, for example, given "cup, source, queen, branch" the participant should respond "branch, cup, queen, source." As with the digit span procedure, participants are first given two lists of two words; if they succeed on at least one of the lists they are given two lists of three words, and so on until they fail both lists at a given length. In the first study (Craik, 1986) we found that age differences were greater on alpha span than on word span, and the sensitivity of alpha span to aging was shown again with larger groups in Craik et al. (2018a).

Figure 8.5 illustrates performance on the alpha span test by participants ranging in age from 17 to 85 years; performance levels peak in the early twenties and then decline steadily across the lifespan. No systematic male/female differences were found somewhat to our surprise, as previous work in my laboratory and elsewhere had found that women typically outscore men on verbal memory tasks.

Interactions with individual differences

James Jenkins, who died in 2012 aged 89 years, was an American psychologist in the best tradition, and one whose ideas have greatly influenced my own thinking; some of his studies are described in Chapter 2. He was a major contributor to associationist theories of memory but gradually became disenchanted with that approach, finally abandoning it in an influential article provocatively entitled "Remember that old theory of memory? Well, forget it" (Jenkins, 1974). In it he argues for *contextualism* as the appropriate framework for memory and cognition, that experience consists of *events*, and that the qualitative meaning of an event is given by its interactions with other events, with other people, and with aspects of the physical world. Another influential chapter by Jenkins appears in the book edited by Cermak and Craik (1979). This one is entitled "Four points to remember: A tetrahedral model of memory experiments" (Jenkins, 1979) and in it

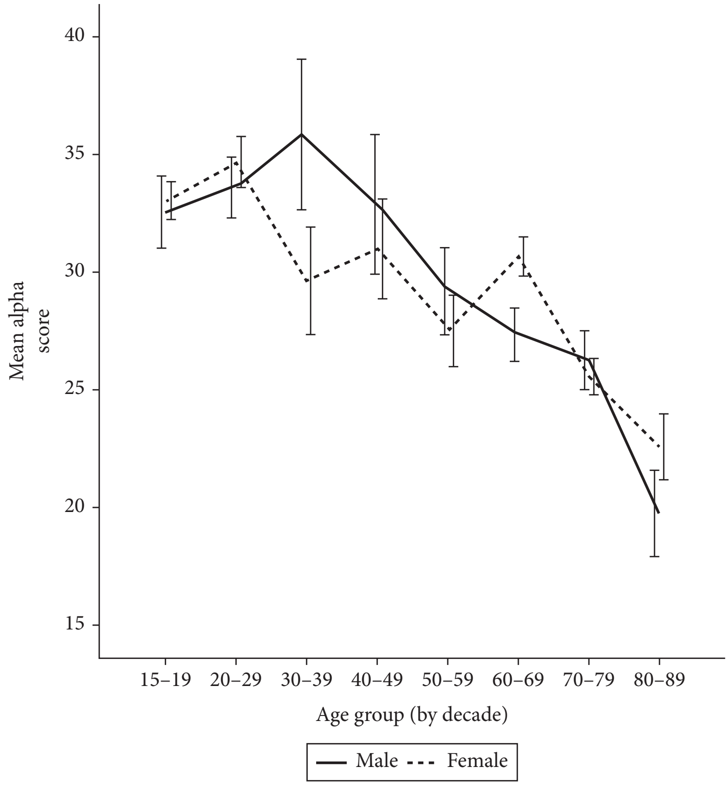

Fig. 8.5 Alpha span scores as a function of gender and age decade .

Reproduced from Craik, F. I. M., Bialystok, E., Gillingham, S., & Stuss, D. T. (2018). Alpha span: A measure of working memory. *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale*, 72(3), 141–152. https://doi.org/10.1037/cep0000143 with permission from APA.

Jenkins emphasizes that to understand the outcome of a memory experiment one must take into account interactions among encoding variables, retrieval variables, characteristics of the material used, and characteristics of participants. It is this last point—the characteristics of older adults and their possible interactions with other variables—that is relevant to the present discussion.

In order to bring "subject variables" into the picture I will describe a study carried out in collaboration with my graduate student Mark Byrd and my colleague James Swanson (Craik et al., 1987). Jim Swanson is a faculty member at the University of California (UC), Irvine, and in the early 1980s he had contacts with an interesting group of older adults who volunteered in the Foster Grandparent Program at Fairview State Hospital in Costa Mesa, California. The program provided a very active and involving environment, and generated strong feelings of group membership among the volunteers. We decided to compare memory

Table 8.1. Characteristics of the four groups (N = 20 per group)

	Old 3	Old 2	Old 1	Young
Age (yr)	76.2	73.5	73.3	19.7
Vocab (WAIS-R)	31.2	35.0	52.2	48.1
% Activity	39.5	57.4	59.0	62.3

WAIS-R = Wechsler Adult Intelligence Scale – Revised.

Source data from Craik, F. I. M., Byrd, M., & Swanson, J. M. (1987). Patterns of memory loss in three elderly samples. *Psychology and Aging*, 2(1), 79–86. https://doi.org/10.1037/0882-7974.2.1.79.

performance in this group with two other groups of older adults of comparable age but with different intellectual and social backgrounds. One group was drawn from affluent homeowners in Orange County, California, and from upper-income residents of a Leisure World retirement community in Orange County. These adults were thus comfortably off economically and socially, and were intellectually and physically active. The third group of older adults consisted of lower income individuals who participated in a federally funded senior citizens' program in Orange County. People in this group were judged to be less mentally and physically active than members of the other two groups. Finally, a fourth group consisted of young adults who were undergraduates at UC Irvine.

Table 8.1 shows the mean ages and WAIS-R Vocabulary (Wechsler Adult Intelligence Scale – Revised) scores of the four groups. The percentages of waking involvement in *active* as opposed to passive pursuits are also shown in the table; active pursuits included golf, visiting others, and doing domestic chores; passive pursuits included resting, reading, eating, and watching TV. In Table 8.1 and Figure 8.6, "Old 3" refers to the senior citizens' group. "Old 2" refers to the foster grandparents, and "Old 1" refers to the relatively affluent seniors. ANOVA on the vocabulary and activity scores showed first that for vocabulary Young = Old 1 and these two groups outscored the Old 2 and Old 3 groups, which did not differ statistically. With regard to activity levels, the young, Old 1, and Old 2 groups did not differ, but all three had higher activity levels than the Old 3 group.

Memory was assessed by means of free and cued recall; lists of 10 common nouns were presented to be learned, in conjunction with compatible cues (e.g., a type of bird—LARK; used in schools—BOOK). In four conditions, the cues were present at both encoding and retrieval (cued–cued), at encoding only (cued–free), at retrieval only (free–cued), or were absent at both encoding and retrieval (free–free). Our assumption was that age- and group-related differences would be greatest in the least supported conditions (free–free) and least in the most supported conditions (cued–cued); additionally, we expected that performance differences among

Condition	Group			
	Old 3	Old 2	Old 1	Young
Cued - cued	5.5	7.3	8.1	7.8
Cued - free	2.2	5.4	5.8	5.8
Free - cued	2.2	4.5	5.3	5.8
Free - free	2.4	4.6	4.7	6.0

Figure 8.6 Word recall scores out of 10 grouped into four levels of performance (Craik et al., 1987, Figure 1).

Reproduced from Craik, F. I. M., Byrd, M., & Swanson, J. M. (1987). Patterns of memory loss in three elderly samples. *Psychology and Aging*, 2(1), 79–86. https://doi.org/10.1037/0882-7974.2.1.79 with permission from APA.

the three older groups would reflect vocabulary and activity levels with Old 1 being best and Old 3 worst.

Figure 8.6 shows the numbers of words recalled out of 10 by the four groups under the four conditions. Performance increased monotonically both between groups (means 3.1, 5.5, 6.0, and 6.3 for Old 3, Old 2, Old 1, and young, respectively) and between conditions (means 4.4, 4.5, 4.8, and 7.2 for free–free, free–cued, cued–free, and cued–cued, respectively). A 4 × 4 ANOVA yielded significant effects of group, conditions, and an interaction between group and conditions. The interaction is illustrated in Figure 8.6 by grouping the recall scores in four performance level bands, 0–3, 3–5, 5–7, and 7–10, and shading boxes containing scores in the same bands. The boxes form a series of "neighborhoods" running from bottom left to top right. For example, the Old 3 group show no improvement in recall as support increases until the cued–cued condition (5.5 words), but the ability to reach the 5–7 band occurs "earlier" as conditions improve from Old 3 to young.

In the article reporting this experiment we concluded that

> the present results underline the point that to get a full picture of cognitive changes with age, it is necessary to look at several different levels of ability; it is not sufficient to compare just one young group with one group of older people. Second, the contextualist position endorsed by the present study implies that models of human cognition that describe only intra-organismic structures and processes (e.g., the influential models of Anderson and Bower, 1973; Atkinson and Shiffrin, 1968; Broadbent, 1958; Craik and Lockhart, 1972) are inherently unsatisfactory; theories of cognitive performance must model the interactions between mental processes and relevant aspects of the environment (Craik et al., 1987, p. 85).

Generality and specificity

It is clear that human knowledge comes in different degrees of generality—from the highly specific representations of recent events to the abstract knowledge concerning classes of events built up from many prior episodes. In my view the episodic/semantic memory distinction of Tulving (1983) and many others is actually better conceptualized as a *continuum* of specificity–generality as proposed by Craik (2007) and elsewhere in the present volume. The basic idea is that the commonalities among similar episodes are gradually represented at a somewhat higher level than the original highly contextual representations. This process of abstraction is then repeated at progressively higher levels, culminating in context-free representations of "general knowledge" formed partly from our own experiences and partly from relevant knowledge passed on from external sources.

With respect to aging, there is good evidence that older adults typically work with representations that are more general than those used by their younger counterparts. Whereas young adults appear to form detailed representations of individual episodes rather effortlessly, such representations require specific instructions in the case of older adults. It also seems that the formation of specific contextualized representations requires the deliberate expenditure of attentional resources; indeed, this may be one major reason for specific representations to occur with greater difficulty in older people. The preference for general information is also obvious at retrieval. Specific detail is less accessible for older adults, as seen in word-finding problems, especially for names of people, plants, animals, places, and objects. Such word-finding problems at older ages are clearly problems of accessibility rather than availability, given that the well-known name typically "pops up" later apparently unbidden but possibly either cued by some change in context or by a change in the direction of mental search ("funny—I was *sure* the name began with an A... ").

What about *evidence* for these claims and conjectures? With regard to effective encoding–retrieval combinations I was first alerted to the drift to generality in older individuals by the work of Eileen Simon who was in my laboratory as a postdoc in 1977–78. For her PhD thesis Eileen had conducted studies of age-related differences in memory in which words were cued at retrieval either by phonemic cues (the word's first two letters) or by semantic cues (meaningful associates). In one experiment the words to remember were presented in sentences, and later recall was either free (no cues) or cued by phonemic, semantic, or contextual cues; the contextual cue was the initial sentence frame. Phonemic cues resulted in improved recall over no cues for both younger and older participants, but whereas the recall performance of young adults was further boosted by semantic cues, these cues were less effective than phonemic cues for the older group. Finally, contextual cues were the most effective cues for the young adults but were substantially poorer than phonemic cues for the older participants (Simon, 1979, Experiment 2). Simon concluded that older adults fail to process verbal information as deeply and elaborately as younger adults, and that in particular older adults fail to integrate the words to be remembered with their specific context—sentences in this case.

These studies were followed up in an experiment conducted by Simon and myself and reported in a book chapter (Craik and Simon, 1980). Words to be remembered were again presented as the last words in sentences, capitalized as a reminder to learn them for a later test; examples are:

> The highlight of the circus was the clumsy BEAR
> The lock was opened with a bent PIN

Subsequent cued recall was either by a general categorical cue such as "wild animal" or "a fastener," or by an adjective cue specific to the encoded sentence—e.g., "clumsy" or "bent" in the preceding examples. The results are shown in Table 8.2.

Again, the result suggest that whereas young adults' encoding processes are influenced positively by the specific context of occurrence, older adults appear to encode words "in the same old way" from one occasion to the next, resulting in an encoded representation that is still "episodic" but is less specifically contextualized than in the case of younger individuals.

The ideas were followed up in an article by Rabinowitz, Craik, and Ackerman (1982) who argued that older adults suffer from a reduction in attentional resources and as a consequence encode events in a more "automatic" default fashion that is less affected by, and less integrated with, the event's specific context of occurrence. As a result (as suggested previously by Eileen Simon), specific contextual cues are less effective for older than for younger participants whereas general categorical cues are equally effective for both age groups. To illustrate these ideas Rabinowitz and colleagues presented younger and older adults with single words and asked them to generate an associate to each word. In two conditions the associates should either be "strong"—defined as one that most people would make—or "weak"—an associate that was uniquely personal to the person. At retrieval, the

Table 8.2. Proportions correct cued recall as a function of age and type of cue

	General Cue (category)	**Specific Cue (adjective)**
Young	0.32	0.44
Old	0.31	0.22

Source data from Craik & Simon (1980). In Poon, Fozard, Cermak, Arenberg & Thompson (Eds.), New directions in memory and aging (pp. 95–112). Hillsdale, NJ: Lawrence Erlbaum Associates.

original words were cued either by the generated associates or by an alternative associate that had not been seen at encoding and was either strongly or weakly associated with a target word. To focus on the main result of interest, when the words encoded with weak (personal) associates were cued with new but strong associates, the young adults recalled 68% of words, only slightly greater than the 63% recalled by older adults. When cued with their own personal associates, performance of the old group remained at the same level (62%), but the young group's recall level rose to 85%, again showing that younger individuals integrate events with their context of occurrence and that this specific context therefore serves as an effective retrieval cue in a subsequent test. More recently, Greene and Naveh-Benjamin (2020) have shown a similar pattern of results for associative information. Older and younger participants were equivalent in their recognition of gist information, but older people were less successful than their younger counterparts in utilizing and retrieving specific information.

The notion that memory encoding is less specific and less distinctive in older than in younger adults has also been shown in the Deese–Roediger–McDermott (DRM) paradigm (Roediger and McDermott, 1995) in which participants falsely recollect a non-presented common associate to a list of related words (for example, if the list contains words such as honey, sugar, and taste, the non-presented word SWEET is likely to be falsely recalled). Evidence supporting older adults' greater vulnerability to false memories in the DRM paradigm was reported by Benjamin (2001) and is in line with analyses by Smith (2006) and by Davidson (2006). One interesting rider on this conclusion is the demonstration by Butler et al. (2004) that whereas older adults generally did make more false-positive errors than young adults in the DRM paradigm, this age difference was found only for low frontal lobe functioning individuals. It seems possible then that an age-related decline in frontal lobe efficiency is at least one major factor behind the more general/less distinctive encoding typical of older adults.

Contextual integration and its consequences

The suggestion that older adults integrate events with their contexts less effectively than their younger counterparts has been documented in several laboratory paradigms. The most straightforward may be the finding that older individuals do not form associative linkages between presented items or events as well as younger adults do. Two classic references in this respect are first a series of experiments by Moshe Naveh-Benjamin (2000), who refers to the concept as the "associative deficit hypothesis," although I would add that the evidence for the effect is strong enough 20 years later to push it beyond the level of a "hypothesis"! Naveh-Benjamin (2001) has also made the point that his studies demonstrating an age-related associative deficit do not always support Craik's claims that the effects of aging can be mimicked by testing young adults under conditions of DA (e.g., Craik and Byrd, 1982; Craik and Jennings, 1992). Another influential article showing that older people do not "bind" features together as effectively as their younger counterparts was published by Chalfonte and Johnson (1996). All in all, the evidence is strongly in favor of an age-related inefficiency in the ability to integrate features to form new items, to form an associative link between two independent events, and to bind events with their context of occurrence.

This last inefficiency is illustrated in the phenomenon of "source amnesia"—the finding that individuals may remember facts they have learned, people they have met, and even events they have witnessed or taken part in, yet forget the episode (or source) in which they first learned that information or experienced the event. Dan Schacter and his colleagues (Schacter et al., 1984) devised a paradigm in which made-up facts about famous and fictional people were read to participants by one of two presenters. The facts were also fictional so if a participant remembered it later, the correct source could only be the first phase of the experiment. Examples of the "fake facts" presented are:

> Bob Hope's father was a fireman.
> Alice Reznak's favorite recreation is yoga.

At the time of retrieval participants were asked questions about the facts (e.g., "What job did Bob Hope's father have?") and they were also asked where they had learned the fact; if they correctly answered "this experiment" they were also asked which of the two presenters had read the statement initially. Relatively easy factual questions were also included among the items tested (e.g., "What sport did Babe Ruth play?"), with the source presumably given as TV or newspaper. Schacter and colleagues tested a group of amnesic patients on the experiment, finding high levels of source amnesia, especially in patients who scored poorly on tests of frontal lobe function. They also tested normal undergraduates with a one-week interval between study and test; the undergraduates exhibited both *item forgetting* and *source forgetting* (i.e., forgetting which person had presented the fact), but "*source amnesia*" (i.e., failing to recollect that the fact had been learned in the experiment) was much less than the level shown by the patients who were tested after a few minutes. Schacter et al. (1984) also stressed the necessity to distinguish item memory from memory of the context (or source) in which the item had been experienced.

Previous discussion in this section suggests that normal older individuals might show an increased tendency to make extra-experimental errors—that is, show signs of source amnesia—relative to younger adults, and also that this tendency might be stronger in older adults who score poorly on frontal lobe tests. These questions were addressed in two studies inspired by the Schacter et al. article; the first study was a collaboration with John McIntyre from the University of Manitoba

(McIntyre and Craik, 1987) and the second was carried out in my laboratory in Toronto (Craik et al., 1990b).

In the McIntyre and Craik study, conducted in Winnipeg, younger and older adults were asked 30 relatively obscure trivia facts about Canadian life. Participants wrote the answer if they knew it; otherwise, they were informed by the experimenter. Half of the questions were presented orally and half were shown on a screen. One week later participants were given a second test of Canadian trivia; this test included the original 30 questions plus 30 new questions that were substantially easier. In the test they attempted to answer each question and were also asked where they learned the fact originally. If they answered "the experiment" they were also asked whether this initial presentation had been oral or visual. Finally, the original 30 questions were presented and participants made a forced-choice decision as to whether it had been presented orally or visually. In the results (Table 8.3), "Knowledge" refers to the proportion of correct answers given to the new questions in the second session; "fact recall" is the proportion of facts *not* known on week 1 that were correctly answered on week 2. "Source recall" for items that were not known on week 1 is split down into the proportion of items that were *correctly recalled* and also correctly attributed to the correct source (oral or visual) within the experiment on week 2, *intra-experimental errors*—correctly recalled items attributed to the wrong experimental source (oral or visual), and finally *extra-experimental errors*—correctly recalled facts misattributed to some external source, e.g., TV, social media, "a friend," etc. Finally, "specific source" refers to the forced-choice test of the original 30 items, so 0.50 represents chance performance.

Table 8.3 shows that the older participants had higher levels of knowledge of the area tested but, despite this advantage in expertise, recalled slightly fewer of the "newly learned" items on the second week. The main results of interest are the age differences in source recall; younger adults scored significantly higher on items correctly attributed to the correct source (oral or visual) within the experiment; the

Table 8.3. Proportions of correct knowledge, fact recall, and source recall for younger and older participants

Participants	Knowledge	Fact Recall	Source Recall			Specific Source
			Correct	Intra Errors	Extra Errors	
Younger	0.33	0.40	0.59	0.30	0.11	0.66
Older	0.46	0.36	0.32	0.24	0.44	0.57

Note: "Intra Errors" refers to intra-experimental errors; "Extra Errors" refers to extra-experimental errors (McIntyre and Craik, 1987).

Source data fro McIntyre JS, Craik FIM. Age differences in memory for item and source information. *Can J Psychol.* 1987 Jun;41(2):175–92. doi: 10.1037/h0084154.

younger group also made significantly fewer extra-experimental errors than their older counterparts. That is, whereas older participants attributed 44% of the newly learned facts to some source other than the experiment, the corresponding figure for younger participants was only 11%. The older group showed substantially more "source amnesia" in this setting.

In order to test the further possibility that within a group of older adults those most vulnerable to source amnesia would score less well on tests of frontal function, we examined the performance of 24 older adults ranging in age from 60 to 84 years (Craik et al., 1990b). The experiment was based largely on the study by Schacter et al. (1984); made-up "facts" about well-known and fictional people were presented to participants who were then tested for memory of the facts and source of their knowledge one week later. Participants were also given the Wisconsin Card Sorting Test (WCST) and the verbal fluency test (generate words beginning with F, A, S)—two tests that are sensitive to frontal lobe pathology (Schacter et al., 1984; Squire, 1982). The measure of source amnesia (the proportion of newly acquired facts correctly remembered a week later that were wrongly attributed to some extra-experimental source) was 0.30. This proportion ranged widely in the group of 24 older adults (from 0.00 to 1.00) and the mean of 0.30 was considerably greater than the comparable value for younger participants (0.07) in the previous study by McIntyre and Craik (1987). Individual differences in the amount of source amnesia correlated with measures of frontal inefficiency; for example, source amnesia correlated significantly with verbal fluency ($r = -.38$), with number of categories scored on the WCST ($r = -.55$) and with number of perseverative errors on the WCST ($r = .42$). However, it should be noted that the level of source amnesia also correlated significantly with age within the adult group ($r = .49$), and when age was partialed out the correlation between perseverative errors and source amnesia dropped to a non-significant ($r = .21$). This result suggests that normal aging is associated with declining frontal functioning (the correlation between age and perseverative errors in the study was $r = .53$) and, in turn, this decline is reflected in an increased liability to exhibit source amnesia. More generally, the results cited in this section show a nice convergence on the ideas that healthy aging is related to a reduction in the efficiency of frontal lobe functioning, that this reduction is associated with inefficiencies in associating (or binding) events to their context of occurrence, and that such failures of integration between events and their contexts result in source amnesia.

Prospective memory and planning

Planning to do things in the future involves mental processes usually attributed to the frontal lobes (e.g., Stuss and Benson, 1986; Luria, 1966; Shallice, 1982), so given the point that frontal functions decline in the course of normal aging it should be expected that both planning for the future and remembering to carry out an intended action at a future time would be impaired in older adults. Work on prospective memory and aging has already been covered in Chapter 5, with the general conclusion that prospective memory is one type of memory that is quite sensitive to the aging process—especially under time-based conditions in which successful remembering is highly dependent on self-initiated processing. The first major study by Einstein and McDaniel (1990) found no age differences, but as experimentation continued, age-related differences in prospective memory *were* found in a variety of situations and conditions (Einstein et al., 1998; Kliegel et al., 2000; Einstein et al., 2000) and a meta-analytic review by Henry, MacLeod, Phillips, and Crawford (2004) confirmed this general finding. A further suggestion made by Einstein and McDaniel (2005) is that age differences are slight if the prospective memory task is *focal*; that is, if the target is the main point of the ongoing task, whereas age differences can be substantial if the target event is *non-focal*, for example, the syllable "tor" in a word categorization task. In a further overview, McDaniel and Einstein (2011) propose a framework in which different prospective memory tasks draw differentially on various components. Some of these components—for example, planning, strategic monitoring, and the necessity to delay a response—will depend on frontal lobe functions and, given the evidence for an age-related decline in these functions, prospective memory tasks involving such frontal processes will be the ones most liable to show age-related declines. This is a very nice series of experiments, starting with a surprising result and gradually revealing the complexities and interactions among participants, materials, and tasks.

I carried out a series of studies on prospective memory in collaboration with Rob West, who was a postdoc in my laboratory from 1996 to 1999, and is now a faculty member at DePauw University in Indiana. One of these experiments (Cohen et al., 2001) was led by Anna-Lisa Cohen who was an undergraduate at the time and is now a faculty member at Yeshiva University in New York. The study set out to examine whether age-related differences in prospective memory were primarily in the prospective component (that is, remembering that some action should be taken) or in the retrospective component (that is, remembering the specific action that should be carried out). The actions (or intentions) in the test phase of the experiment were real-life intentions such as "make an appointment to see the doctor" and "pick up dry cleaning." In the encoding phase each intention was paired with a prospective cue that was either a word alone or a word with its illustrative picture. Additionally, the word-alone cues and picture + word cues were either related or unrelated to the intention. For example, for the intention "make an appointment to see the doctor" the related word cue was "surgeon" and the picture + word cue was "surgeon" plus a picture of a surgeon. In the unrelated condition the word cue was "balloon" and the word + picture cue was "balloon" plus a picture of a balloon. In the test phase *all* cues were presented as pictures, so even when "balloon" had been presented in the study phase as a word alone, at test the cue was shown as a picture.

In the picture + word cases, the same picture was re-presented as the cue. In all, 24 prospective cue pictures were shown in the test phase, six for each of the four conditions, word alone/word + picture × related/unrelated. These 24 prospective picture cues were shown interspersed randomly with 48 completely new distracter pictures plus 72 pictures that participants had also learned in the study phase in a background picture–word paired-associate task (e.g., picture of a kettle paired with the unrelated word "donkey"). This paired-associate task was given to provide distraction during the test phase. So during the test phase participants were presented with 144 different pictures and their primary task was to recall the words associated with the paired-associate pictures, also to reject the completely new pictures, and to detect the pictures that had been presented as prospective cues. In this last case they also had to recall the intention paired with the prospective cue. The main measures of interest were, first, the proportions of prospective cues detected (the "prospective component") in the four different conditions by younger and older adults, and, second, the proportions of correct intentions recalled given detection of the relevant prospective cue (the "retrospective component").

Results for the prospective component are shown in Figure 8.7. The prospective component was simply the proportion of prospective memory cues actually detected in the test phase, regardless of whether the associated intention was correctly recalled. The figure shows that younger participants outperformed older participants, the picture + word conditions were associated with higher scores than the word-only conditions, and that relatedness had little effect on performance in

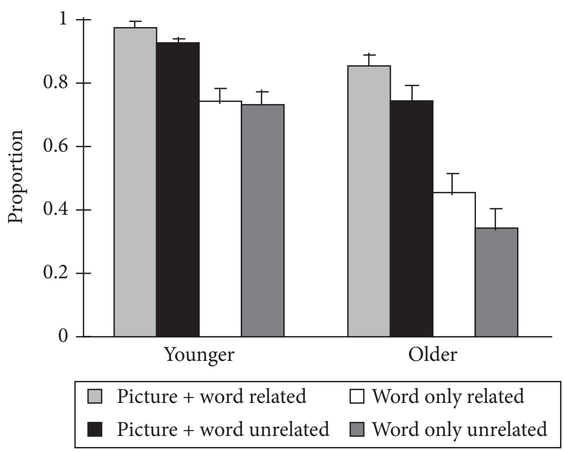

Fig. 8.7 Proportions of prospective memory cues correctly detected as a function of age group and experimental condition (Cohen et al., 2001, Experiment 2).

Reproduced from Cohen, A.-L., West, R., & Craik, F. I. M. (2001). Modulation of the prospective and retrospective components of memory for intentions in younger and older adults. *Aging, Neuropsychology, and Cognition*, 8(1), 1–13. https://doi.org/10.1076/anec.8.1.1.845 with permission from Taylor and Francis.

the younger group but did have an effect on the older group. These three main effects were all statistically significant, as was the interaction of age and study-test format—age differences were greater when study cues were words only. The age × relatedness interaction was not reliable.

The retrospective component was calculated as the proportion of correct intentions recalled given detection of the associated prospective memory cue. In this case, all three main effects were significant—age, relatedness, and study-test format—but there were no reliable interactions. It is worth noting that when performance on the two components was compared, the effect of relatedness was greater on the retrospective component (for prospective, the value of Cohen's *d* was 0.80, whereas for retrospective the comparable value of *d* was 2.54), but the effect of age is greater on the prospective component (for prospective, the value of Cohen's *d* is 1.76, whereas for retrospective the comparable value of *d* is 1.05). In this case at least the age-related decrement in prospective memory was greater in the prospective component (realizing that some action is required) than in the retrospective component (recollecting the appropriate action). Admittedly, the laboratory-based nature of the task likely differs from real-life situations in which there may be no need to monitor the environment for prospective cues. Another point is that the experiment is one in which substantial age-related decrements were found in a prospective memory task despite the fact that the task was event-based. It is also another case in which the age decrement is greatly reduced when external support is provided—that is, when prospective picture cues were re-provided at test. In Figure 8.7 compare the age differences in the *words only/unrelated* condition shown by the rightmost bars with the *picture + words/related* condition shown by the leftmost bars.

Age differences in implicit and explicit word-fragment completion

This study was run by Nigel Gopie, who was a postdoctoral student supervised jointly by Lynn Hasher and myself; he subsequently went on to a highly successful career as a global leader with IBM Food Trust. The experiments are described in an article by Gopie, Craik, and Hasher (2011) and were initially undertaken to further explore aspects of Hasher and Zacks' proposal that older adults are less able to inhibit irrelevant information (Hasher and Zacks, 1988; Hasher et al., 1999). This age-related impairment in inhibitory control follows very reasonably from what we know about the negative effects of aging on frontal lobe processes and executive control (e.g., Cabeza and Dennis, 2012). In the first experiment by Gopie et al., groups of younger and older adults first carried out a color-naming exercise in which 50 words and random letter strings were presented visually. The words and non-words were colored red, green, blue, or yellow, and the participant's task was simply to respond to each color by pressing the appropriate button on a response box as rapidly as possible. They were told to concentrate on the colors and that the words and non-words were irrelevant to their task.

Following a 10-minute interval in which participants performed a non-verbal task they were given a list of 30 word fragments to solve. The list of word fragments contained 10 that could be completed from the previous color-naming task, 10 further word fragments of comparable difficulty, and 10 filler fragments that were relatively easy to solve. Half of the participants from each age group were given the word fragment completion (WFC) task under implicit memory conditions, and half under explicit memory conditions. Participants in the first group were instructed simply to write down the first word that occurred to them as a completion of each fragment, and those in the second group were informed that some of the fragments could be completed from the previous color-naming task, and to use these previous words whenever possible. With regard to the implicit version, our idea was that if older participants were less able than their younger counterparts to inhibit the "irrelevant" words in the color-naming task, they might be more successful in the word fragment task. As shown in Table 8.4, this was the result we found. Once baseline performance was taken into consideration (calculated from completion of the 10 new fragments of comparable difficulty) the proportions of successful completions were 0.25 and 0.10 for older and young participants, respectively. A result nicely in line with the Hasher and Zacks' view, although note that the younger adults did show *some* priming under implicit conditions, suggesting that inhibition of the previous irrelevant words was not perfect.

With regard to the explicit fragment completion task, it was less obvious what to expect; if younger participants successfully inhibited words from the color-naming task they should be able to complete the 10 target fragments no better than the 10 new baseline fragments, whereas older participants might replicate the more successful performance shown by older individuals in the implicit group. The actual results were surprising (Table 8.4); the pattern of priming completely reversed, with young adults now scoring 0.24 and older adults only 0.08—less than the 0.25 shown by the implicit group. One known difference between implicit and explicit fragment completion is that the former is sensitive to perceptual priming (that is, completion is aided when previously presented words are processed in a manner that emphasizes their perceptual characteristics), whereas the latter is sensitive to conceptual priming—when previously presented words are processed semantically (Craik et al., 1994). One line of explanation of the current results is that older adults processed the initial color words in a shallow perceptual manner, whereas younger adults processed at least a few of these initial words in a deeper more conceptual manner. This possibility fits the finding that older adults did relatively well on the implicit WFC task but poorly on the explicit task, whereas younger adult show the opposite pattern.

Table 8.4. Proportions of target and baseline word fragment completions, and overall memory performance in Experiments 1, 2, and 3 (Gopie et al., 2011)

Measure	**Experiment 1 (between-subject design)**		**Experiment 2 (within-subject design)**		**Experiment 3 (within-subject design)**
	Younger adults	**Older adults**	**Younger adults**	**Older adults**	**Younger adults with divided attention**
Target completions					
Implicit test	.21 (.15)	.33 (.09)	.25 (.16)	.36 (.14)	.41 (.15)
Explicit test	.38 (.14)	.27 (.16)	.41 (.15)	.27 (.13)	.24 (.15)
Baseline completions					
Implicit test	.11 (.09)	.08 (.07)	.23 (.16)	.19 (.15)	.19 (.11)
Explicit test	.14 (.13)	.19 (.12)	.23 (.15)	.24 (.12)	.27 (.19)
Memory performance (target—baseline)					
Implicit test	.10 (.12)	.25 (.08)	.02 (.19)	.17 (.18)	.22 (.19)
Explicit test	.24 (.12)	.08 (.14)	.18 (.19)	.03 (.16)	−.03 (.30)

Reproduced from Gopie N, Craik FIM, Hasher L. A double dissociation of implicit and explicit memory in younger and older adults. Psychol Sci. 2011 May;22(5):634–40. doi: 10.1177/0956797611403321 with permission from SAGE Publishing.

In their second experiment Gopie et al. (2011) basically replicated Experiment 1 in a within-subject design. This yielded the same pattern found in the first experiment, with priming scores for older adults being 0.17 and 0.03 for the implicit and explicit WFC tasks, respectively; the corresponding scores for younger adults were 0.02 and 0.18. Thus, older adults again showed priming for implicit but not explicit WFC whereas younger adults showed the opposite pattern. A third experiment explored the notion that the result in older adults is attributable to their relatively shallow processing of the initial color-naming words. The experiment involved young adults only but had them process the initial color-naming words under conditions of divided attention (DA); specifically, the words were presented visually, color decisions were registered by button presses, and participants simultaneously listened to a long string of auditory digits for targets defined as three successive odd digits—e.g., 3–9–1 and 5–7–5. Our expectation (based on work reported in Chapter 4) was that younger adults performing under DA would behave like older adults, and might therefore show implicit but not explicit priming. This result was, in fact, obtained: Priming scores were 0.22 for implicit WFC and –0.03 for explicit WFC; the negative score simply means that the group solved fewer target fragments (0.24) in the explicit case than new (baseline) fragments (0.27).

Results of the three experiments reported by Gopie et al. (2011) are thus in line with the suggestion that older adults fail to inhibit the irrelevant words in the color-naming phase but that such word processing is relatively shallow and perceptual in nature. In turn, this leads to successful implicit priming but unsuccessful explicit priming. This account fits well with the Hasher and Zacks view that aging is associated with declining effectiveness of inhibitory processes. The results from the young groups are less easily understood. They suggest that the initial color words were not merely processed perceptually except under DA conditions in Experiment 3, but that some degree of lexical conceptual information did get processed, enabling participants to complete at least some word fragments (0.38 in Experiment 1 and 0.41 in Experiment 2). This "leakage" of conceptual information for irrelevant items is somewhat contrary to the Hasher and Zacks view of effective inhibition in young adults (see Amer et al., 2018, for more on this point). I must say that I also find it difficult to accept that younger adults should process conceptual information but not perceptual information in the color-naming task.

An alternative line of argument suggested by Gopie and colleagues—and one that I personally find more attractive than the differential leakage notion—is that younger adults have more control of their memory retrieval processes than do their older counterparts (Jacoby et al., 2005b). It seems likely that when presented with an implicit WFC task that bears no relation to the earlier color-naming task (as far as they know), younger adults will use the fragments to generate possible completions from their general lexical knowledge; that is, they focus actively on their knowledge of word structures. When they are informed that words from the previous task may help, however, they attempt to retrieve possible candidates from words they may have noticed while performing the color-naming task, and are apparently successful in some cases. Older adults presumably also make the same attempt but in their case unsuccessfully. Given that WFC performance (unlike performance on explicit tests of memory) is better at *off-peak* times of day when attentional regulation is least efficient (Rowe et al., 2006), it seems possible that when older adults attempt to complete word fragments effortfully by attempting to recollect the previously ignored words, such effortful attempts actually impair their WFC performance.

In my view the most intriguing result from the Gopie et al. (2011) article is the large increase in priming scores (an average of 0.06–0.21) in young adults when shifting from implicit to explicit conditions (Experiments 1 and 2 in Table 8.4). Clearly, these experiments must be repeated with other materials, especially given that Amer et al. (2018) did not replicate the result. If the finding *is* replicated, two possible lines of explanation are first that younger adults do, in fact, process some conceptual information from the initial task under incidental processing conditions, and second that lexical information is present at retrieval in both conditions but is used by younger adults only when informed of its relevance. The plausibility of the second point is in line with the flexibility of retrieval strategies in young adults demonstrated by Jacoby et al. (2005a), and also in an earlier "release from proactive interference" study by Gardiner, Craik, and Birtwistle (1972) described in Chapter 6.

There is also a need to replicate the similarity in pattern between older adults working under full attention (FA) and younger adults working under DA during incidental encoding of words in the initial phase. A confirmation of the pattern obtained by Gopie et al. (2011) would add further weight to the proposed processing similarity between young–DA and old–FA discussed earlier in this chapter. On a related point, the striking differences in WFC performance shown by younger adults encoding initially under FA as opposed to DA (comparing Gopie et al., 2011, Experiments 1 and 2 to Experiment 3) strongly suggests that younger adults do *not* totally inhibit the irrelevant words under FA conditions. The effect of DA at encoding may be to emphasize processing of perceptual aspects in a manner that is at least different from processing under FA. If young adults completely inhibit processing of irrelevant words under normal (FA) conditions, the addition of a secondary task should make no difference to performance on a subsequent test. In conclusion, the results reported by Gopie et al. (2011), while controversial, do suggest some interesting questions about age-related differences in retrieval under implicit and explicit conditions.

Summing up

These last two chapters have covered a lot of ground—probably because roughly half of my work on memory has dealt with age-related differences—so it may be helpful to review the main arguments. The most general point is that whereas there definitely *are* age-related impairments in memory performance, these impairments are greater in some tasks than in others. Decrements are substantial in WM, in episodic memory, prospective memory, and in memory for source or context; but age-related decrements are relatively slight in the recency effect and related primary memory paradigms, in recognition memory, and in many procedural memory tasks. Age differences are also often small in tests of knowledge or semantic memory (see, for example, Salthouse, 1982), but this conclusion may be tempered by such factors as recency of access and the specificity of information sought; that is, older adults may have difficulty in retrieving information they have not thought about for some time and also experience difficulty retrieving names and other highly specific details. These striking task differences may suggest an interpretation in terms of the differential effects of aging on different memory systems (e.g., substantial differences in episodic memory, and much smaller differences in semantic and procedural memory). This is clearly a possible approach to understanding age differences, but I have preferred to tackle the problems by invoking such process-related concepts as processing resources, executive functions, self-initiated activities, and environmental support.

In my opinion, the major factors underlying age-related declines in memory and cognition are biological in nature. I do not doubt the existence of "cohort effects"—the idea that individuals who are now 70 or 80 experienced educational, health, social, and cultural environments that were very different from the environments experienced by today's young adults of 20 or 30. I also believe that these environmental differences do play some role in the cross-sectional age-related changes observed in many laboratory studies. One source of evidence for this latter position is the smaller age-related changes in memory performance typically observed in longitudinal studies compared with cross-sectional studies—in middle-age adults at least (see Salthouse, 2010, for a review). More work is clearly needed to document the independent and interactive contributions of biological and cultural changes to cognitive aging; the late (and very wise) Paul Baltes made a start to this enterprise under the somewhat daunting banner headline of "biocultural co-constructivism" (Baltes et al., 2006). Nonetheless—there is just so much work now linking age-related decrements in brain structure and function to corresponding decrements in memory performance (e.g., Cabeza et al., 2016; Nyberg et al., 2012; Gorbach et al., 2017) that my bias (if you like) is to think of age-related cognitive changes as essentially reflecting changes in the underlying biology.

Two such postulated changes that have played a large part in my thinking about age-related declines in memory are a reduction in available processing resources and a reduction in self-initiated activities. I think of "processing resources" as the general-purpose fuel needed by neural networks to function effectively and so enable the cognitive processes they map onto to perform operations that may be characterized as richly elaborate and specific in a variety of processing domains. What *exactly* these processing resources are is still a matter for conjecture and debate; they seem to be intimately bound up with attention, with attentional processes serving both to select one processing domain over another, and also to provide the "mental energy" to activate the selected processes in an effective manner. The evidence described in the present chapter was based, to some extent, on the parallel between the effects of aging and the effects of DA on various types of processing. Both aging (Cabeza et al., 1997a; Grady et al., 1995) and DA in young adults (Shallice et al., 1994) are associated with reductions in the activation levels observed in the left inferior frontal gyrus, and in turn this activation is related to the processing of meaning (Kapur et al., 1994; Petersen et al., 1988; Raichle et al., 1994). So, one main claim of the present argument is that age-related memory decrements are due, in part at least, to a reduction in the amount of attentional resource available to older individuals.

Other related points are first the observation that neither aging nor DA reduces the effectiveness of relatively shallow processing operations—for example, the articulatory rehearsal of the last few works in a free recall list. The recency effect is essentially unaffected by both aging (Craik and Jennings, 1992) and DA (Craik, 1982). Thus, attentional resources are required for deeper, inferential processing that goes beyond the information provided in the stimulus (Till and Walsh, 1980). If we think of incoming processing proceeding in a hierarchical manner from sensory analyses to the analysis of meaning, implication, and response selection (Craik and Lockhart, 1972; Treisman, 1960, 1964a) it seems that attentional resource requirements become greater with increasing depth of processing. A second point discussed earlier in the chapter is the "compensatory" effects provided by pictures and semantic orienting tasks—especially when coupled with recognition at the time of retrieval (e.g., Craik and Byrd, 1982; Craik and Schloerscheidt, 2011; White described by Craik, 1977a). My account of these effects is that depth and elaboration of processing depend on an interaction between the material and the manner in which it is presented on the one hand and the processing operations carried out on that material on the other. If the presented stimuli are rich and meaningful in terms of many past experiences—such as pictures or scenes—they will invoke or even "drive" a deep and elaborate set of cognitive operations without the need for effortful and resource-demanding operations initiated by the perceiver. Similarly, deep orienting tasks have their effect by steering and supporting processing operations (e.g., questions that necessitate semantic processing to find the answer). My suggestion then is that pictures and deep orienting tasks do not somehow "provide more resources," rather they bypass the *need* for resources by invoking well-learned meaningful operations built in to the cognitive system by years of meaningful transactions with the outside world (see also Baddeley and Hitch, 2017).

In previous years there was some debate among researchers on the question of whether age-related differences in memory were attributable primarily to inefficiencies of encoding or retrieval. Some individuals (e.g., Craik and Jennings, 1992) stressed the former, whereas others (e.g., Burke and Light, 1981) stressed the latter. It now seems clear that there are age-related impairments in both sets of processes—conceivably stemming from the same root problem, in that a decline in attentional resources may underlie failures to locate and reconstruct information that is difficult to access at retrieval, as well as failures to encode deeply and elaborately. As discussed earlier in this book, I assume that retrieval processes function essentially to reinstate the same processing operations that were involved during an event's initial occurrence, or during the conscious apprehension of factual knowledge. It follows that this reinstatement ("repetition of operations" in Kolers' terms) will be facilitated to the extent that the relevant information is re-provided in the shape of cues, reminders, and reinstatement of context. To the extent that such information is lacking, it must be reconstructed by the person attempting to remember, and the success of such reconstructive operations will depend on the efficiency of self-initiated activities. My suggestion has been that such activities depend on the integrity of frontal lobe processes, and that these are less efficient in older adults. The corollary is that older people are therefore more dependent on environmental support and benefit differentially when such support is available. Evidence in support of this position was presented earlier in the chapter.

In general, it is probably the case that experimental psychologists (and indeed others!) have been too prone to look for and find evidence for their own particular theoretical position and to ignore or question the positions of colleagues. In the case of memory and aging, it seems likely that a number of factors combine and interact to affect the efficiency of encoding, retention, forgetting, and retrieval. Many of these factors reflect the integrity and efficiency of associated neural mechanisms, but others may reflect attitudes, strategies, and cognitive styles shaped by the individual's personal history and experience. Apart from the concepts of processing resources and environmental support emphasized in the present chapter, other factors related to age-related memory problems have included losses in executive functions, inhibitory efficiency, and cognitive control (Hasher et al., 1999; Jacoby, 1991; Jennings and Jacoby, 1993; Stuss and Craik, 2020). A final obvious factor in cognitive aging is age-related slowing of essentially all aspects of perception, memory, thinking, and responding—a factor highlighted over the years by Tim Salthouse (1981, 1982, 1996). It seems very likely that losses in neural volume, effectiveness, and connectivity result in the slowing of cognitive processes, and that this factor in turn reduces the older person's ability to encode and retrieve information; Salthouse (1996) has suggested ways in which this may happen. However, it also seems possible to me that some aspects of age-related slowing may be the *result* of age-related impairments in executive functions, cognitive control, association formation, and other cognitive processes, rather than being the fundamental causative factor. Further research will shed light on such problems, but meanwhile the field will be better served to the extent that researchers adopt a multifactor approach to problems of cognitive aging.

9
Neuroimaging Studies

I have talked almost exclusively in this book about remembering as an "activity of mind," but it is clear that remembering must also be an activity of the brain. The experiences and behaviors associated with remembering must, presumably, be underpinned by a parallel set of activities at the level of neural networks—an assumption endorsed by Donald Hebb (1949) in his theory of cell-assemblies (see Chapter 2). My own background and interests have led me to study human memory largely at the level of cognitive behaviors, but I have also been involved in a number of cognitive neuroscience experiments over the years, mostly in the role of cognitive adviser. Neuroimaging studies now play a major role in human memory research, however, so the inclusion of a chapter on the topic seemed both timely and relevant. My main purpose was to document the evidence from such studies on topics highlighted in previous chapters, and to assess the extent to which the results increase understanding of the relevant issues. For example, what are the correlates of deeper processing, and does the neuroimaging evidence illuminate the reasons for the strong relation between semantic processing and good memory? Is there evidence to support the proposal that retrieval processes recapitulate encoding processes? I have stressed the similarity between perception and memory—is this borne out at the neural level? How does novelty affect memory, and is there a conflict between the claims that both novel and familiar experiences are associated with good levels of recollection? What exactly *are* processing resources at the neural level? And finally, given my emphasis on remembering as an activity, how does this proposal square with the evidence from neuroimaging studies?

Levels of processing in the brain?

In the early 1990s the Department of Psychiatry at the University of Toronto acquired both a positron emission tomography (PET) machine and a young neuropsychiatrist named Shitij Kapur who had worked with PET scanning in the UK. Dr. Kapur is both an excellent scientist and an outstanding administrator; he is now the Dean of Medicine, Dentistry and Health Sciences at the University of Melbourne. Fortunately for us in Psychology, Shitij was interested in the

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neuroscience of memory and so contacted Endel Tulving, Morris Moscovitch, and myself with a view to setting up a series of exploratory experiments. One study (Tulving et al., 1994) examined brain differences between encoding and retrieval processes, with the finding that left prefrontal regions were differentially more activated during encoding operations, whereas right prefrontal regions were more involved at the time of retrieval. This observation was confirmed by other researchers, and was labeled the hemispheric encoding/retrieval asymmetry model (HERA) by Endel Tulving. The finding of *different* brain regional activities during encoding and retrieval at first seems contrary to the notion that retrieval operations recapitulate encoding operations (Craik, 1983; Kolers, 1973), but Tulving and colleagues suggested that this differential prefrontal involvement might reflect the operation of different strategic or supervisory functions during memory acquisition and retrieval, rather than processes representing the memory operations themselves.

A second study in the same series (Kapur et al., 1994) explored the levels-of-processing (LOP) paradigm. Participants viewed long lists of nouns in the scanner and in one condition judged whether the nouns contained the letter "a" (shallow processing) or, in a second condition, whether the nouns represented a living thing (deep encoding). The subtraction of shallow from deep patterns of brain activity revealed a strong region of activation in the left inferior prefrontal cortex (PFC). The cognitive significance of this left PFC activity (Figure 9.1) has been debated

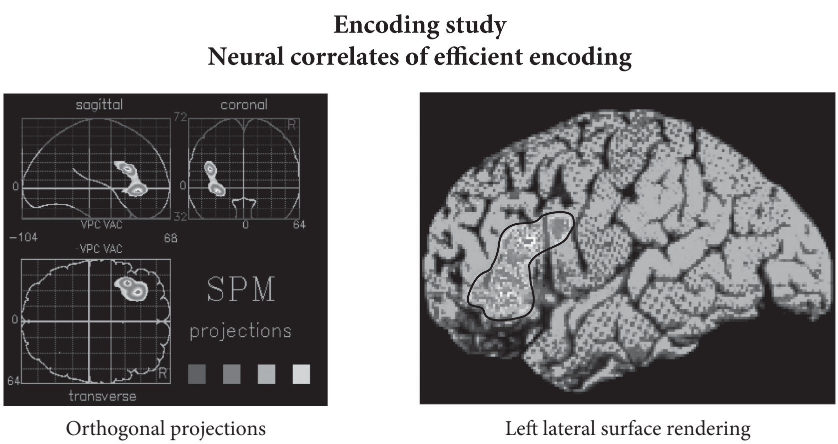

Fig. 9.1 Area of left prefrontal activation associated with deep levels of processing; semantic minus perceptual processing.

Source data from Kapur S, Craik FIM, Tulving E, Wilson AA, Houle S, Brown GM. Neuroanatomical correlates of encoding in episodic memory: levels of processing effect. *Proc Natl Acad Sci U S A*. 1994;91(6):2008–2011. doi: 10.1073/pnas.91.6.2008.

for some time. A group from Washington University in St Louis (Petersen and Fiez, 1993; Petersen et al., 1989) had shown that the same region was activated in a language processing paradigm in which participants either simply repeated a noun (FOOD—"food") or generated a verb appropriate to the presented noun (FOOD—"eat"). The generate condition was associated with activation in the left inferior PFC, but this activation was absent in the repetition condition. The activated area had essentially the same brain coordinates as the region associated with deeper processing found by Kapur et al. (1994), as shown by the similarities between Figures 9.1 and 9.2. The studies by Petersen and colleagues were concerned with lexical processing and not memory, however, so Tulving and I repeated their study with their material, but added a memory component (Tulving et al., 1994). Student participants were given four lists of 20 nouns printed on sheets of paper and were asked to simply copy each noun on two of the lists, and to generate appropriate verbs for each noun on the remaining two lists. Speed of completion was emphasized, and no mention was made of any later memory test. Five days later the students were given a recognition memory test for the 80 nouns mixed with 80 new nouns; the hit rates for copy nouns and generate-verb nouns were 0.26 and 0.50, respectively. Thus, yet again, the greater semantic involvement associated with generating an appropriate verb resulted in higher levels of memory performance.

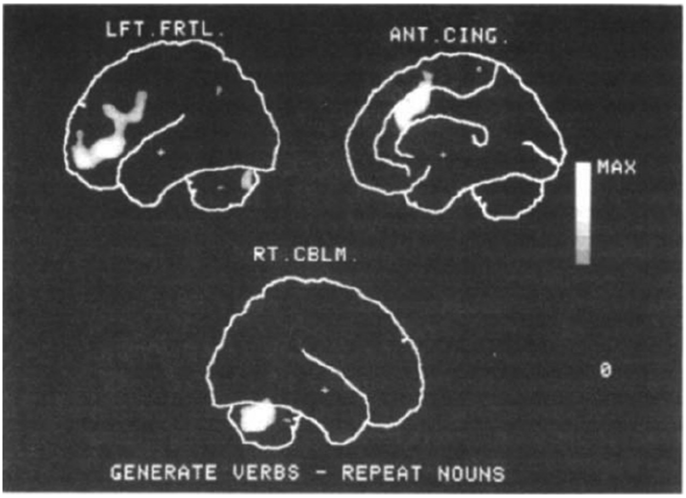

Fig. 9.2. Areas of activation associated with semantic processing; verb generation vs. noun repetition. Compare the top left diagram with Figure 9.1; there is a striking resemblance between the patterns of activation in the left inferior prefrontal regions.

Reproduced from Petersen SE, Fiez JA. The processing of single words studied with positron emission tomography. *Annu Rev Neurosci.* 1993;16:509-30. doi: 10.1146/annurev.ne.16.030193.002453 with permission from Annual Reviews.

In light of various behavioral results, Petersen and Fiez suggested that some computation related to semantic processing or association between words gives rise to the left PFC activation. Additionally, it has been shown that the level of this activation decreased when paired-associate learning was performed concurrently with a difficult distractor task, compared to the level of activation associated with an easy distractor task (Shallice et al., 1994). That is, division of attention at encoding reduces the level of activation in the left PFC. Activation in this area was also reduced in older adults versus younger adults during meaningful encoding of words (Cabeza et al., 1997b; Grady et al., 1999) and faces (Grady et al., 1995). Given that the left prefrontal activation occurs in a variety of cases of meaningful processing, and is reduced in cases where such processing is plausibly impaired (aging, division of attention), it seems reasonable to suggest that the activation reflects deep semantic processing.

Another PET study, among several carried out at the Rotman Institute in the 1990s, confirmed these early results and extended them to older adults. Cabeza et al. (1997a) tested groups of younger and older adults while they encoded and retrieved lists of word pairs. The younger participants showed activations in left prefrontal and occipital–temporal regions during encoding, and in right prefrontal and parietal regions during retrieval, thereby replicating the HERA model. This pattern was not shown by the older participants, however; they showed little PFC activity during encoding, but activations in both left and right frontal areas during retrieval. The age-related reduction in left frontal activity during encoding supports the suggestion (see Chapter 7) that older adults encode verbal material less deeply and less elaborately than do their younger counterparts, and that this relative inefficiency results in their poorer subsequent memory performance. The *increased* left frontal activity in older participants during retrieval was speculatively attributed to compensatory mechanisms by Cabeza et al. (1997a), although this suggestion remains controversial (Morcom and Henson, 2018).

The search for self

Episodic memories relate to events in the individual's own personal history; thus, they all deal with the past and they all contain feelings of self. In conversations with my friend Boris Velichkovsky of Dresden and Moscow I had learned that disorders of self-awareness are often associated with damage to the right PFC (Luria, 1973; Stuss, 1991). In the HERA model described earlier, Tulving et al. (1994) proposed that the left PFC was associated with encoding processes, whereas the right PFC was activated during episodic retrieval. After talking with Boris I wondered whether the right PFC involvement might actually be reflective of the "self" component of retrieval rather than of retrieval processes generally.

Some Rotman Institute colleagues and I decided to investigate this possibility in a PET study using the self-reference paradigm described in Chapter 4. In our version (Craik et al., 1999), participants were shown a series of trait adjectives (e.g., *stubborn*, *joyful*, *enterprising*) and responded on a 1–4 scale. In different conditions, participants were asked to rate either how well the adjective described them personally (*self*), how well it described a well-known other person (*other*; we chose Brian Mulroney, the Canadian Prime Minister at the time), how socially desirable the trait was (*general*), or how many syllables the adjective contained (*syllable*). This last condition provided a measure of shallow encoding; the remaining three conditions involve semantic processing in a descending order of personal reference from *self* to *other* to *general*. For the first three questions the possible scale responses were 1 = never, 2 = rarely, 3 = sometimes, and 4 = almost always; for the syllable condition, responses 1–4 referred to adjectives with 2, 3, 4, or 5 syllables, respectively. Each of the four conditions was performed twice in the scanner. After scanning was completed, participants were given an unexpected recognition test for the adjectives they had processed, in a long list containing the same number of new trait adjectives.

The results of the recognition test, expressed as hits minus false alarms, were self = 0.59, other = 0.50, general = 0.51, and syllable = 0.29. Analysis of these results showed that the three semantic conditions were significantly superior to the syllable condition but did not differ statistically among themselves, possibly owing to the small number of participants (N = 8) involved in the (very expensive!) PET study. Brain activity patterns were assessed by subtracting syllable scan results from each of the semantic conditions. In overview, all three comparisons showed increased activity in medial and *left* prefrontal areas, thereby giving support to the original HERA model, and discounting the possibility that self-processing involved *right* prefrontal regions. These PET analyses were conducted using statistical parametric mapping (SPM) software; further analyses using partial least squares (PLS) software generally confirmed the SPM results. However, a PLS analysis contrasting the self-condition with the other three conditions demonstrated specific self-related activations that were located predominantly in the right frontal lobe. This final result offered at least a crumb of comfort to our original idea.

Since the time of our early PET experiment many subsequent neuroimaging studies have sought to pin down the elusive "self" in the brain's capacious folds. A meta-analysis by Denny et al. (2012) revealed that the predominant locations associated with self-reference were medial PFC, the left temporal–parietal junction area, and the posterior cingulate. Gilboa and Moscovitch (2017) proposed that the brain representation of self may take the form of a superordinate cognitive schema, bringing together many aspects of personal experience. Further, this schema, located primarily in the medial PFC, acts to influence ongoing processing at both encoding and retrieval (see also Andrews-Hanna et al., 2014). In retrospect, I would now agree that the brain correlates of "self" are more likely to be represented by widespread neural networks than by a self-contained module. Otherwise, this modern neuroimaging quest for the self becomes too reminiscent of medieval attempts to locate the soul in the human body!

Perception and memory

Traditionally, perception and memory have been viewed as separate "faculties of mind." One major distinction refers to time: perception deals with the present, whereas memory refers to the past, and can be applied to the future. Additionally, they seem to perform different functions; perception enables us to know what's out there in the environment, and enables navigation, communication with others, the achieving of goals, and the awareness of danger. Memory, however, serves as a store for our accumulated experiences and abstracted knowledge of the world, as well as a way to recollect favored locations and to avoid dangerous locations. A dichotomy between the two faculties also seems clear on the basis of findings from brain-damaged patients; perception can be damaged without memory loss and vice versa. The famous hippocampal patient HM provided a classic example of the latter case; his perceptual abilities were intact, yet his memory for new events was essentially zero.

The perception–memory dichotomy has recently been questioned, however; see Murray, Wise, and Graham (2017, pp. 235–255) for excellent coverage of the topic. One of their points is that the perirhinal cortex (in the medial–temporal region) has traditionally been regarded as a structure mediating memory functions; it is one structure that was damaged (or disconnected; see Murray et al., 2017, pp. 397–400) in the patient HM. However, the perirhinal cortex also has sophisticated perceptual functions—for example, enabling discriminations between pairs of very similar objects—and HM was indeed impaired on such tasks (Murray et al., 2017, p. 237). On the basis of this and other evidence from monkeys, rats, and humans, Murray and colleagues conclude that perception and memory are, in fact, closely connected, proposing that the perirhinal cortex and the hippocampus evolved to *process* and *store* specialized representations, and that they function both to discriminate among similar objects and to aid in navigation.

While discussing these issues with my perceptive (and discriminating!) colleague Brad Buchsbaum, he commented:

> One might say that irrespective of whether one is perceiving an item through direct sensory contact or recalling that object in memory, the same "specialized representations" must be activated. So if the specialized representations are required for discrimination, then by this argument they are also needed for a faithful reconstruction of a complex object or navigational route. Put another way, to discriminate between two complex objects differing on some feature conjunction, your brain needs access to a complete model of the two objects. To retrieve these same objects in memory the brain also needs a complete model of the objects, so that it can reconstruct their hierarchical sets of features in the neocortex. So perception and memory need the same "representational stuff" to do their work (Buchsbaum, personal communication, 2020).

One further point that arises from Murray and colleagues' analysis of perirhinal functions is that animals with perirhinal lesions are particularly prone to making false recognition errors to stimuli that share low-level visual features with wanted items (Murray et al., 2017, pp. 243–245). They argue that the lesions prevent the build-up of sophisticated representations involving high-level features in memory, and that encounters with items similar to target items evoke a sense of familiarity because of the overlap of low-level features. In turn, this misplaced familiarity leads to false recognition. These findings make an interesting connection to a patient with severe memory problems whom we studied in my laboratory (Craik et al., 2014). The female patient known as VL was in her early eighties, and had exhibited bizarre memory problems for several years. These problems took the form of claiming she had experienced objects and events beforehand in situations where that was not possible. For example, when family members showed her photos from a trip they had just been on, VL claimed she had seen them all before. Similarly, she would turn off TV news items because again "she had seen them already." During car trips or shopping excursions to new locations she would point out total strangers and make comments such as "That man is always standing on that same corner—you'd think he would have better things to do!" And on one occasion when I was escorting her to my laboratory for testing she was startled by a young female jogger who brushed past her on the sidewalk; VL exclaimed "She's always doing that—she should be more careful!" In the laboratory, one test we gave her was picture recognition in which 112 pictures from magazines were shown one at a time, with 23 of the pictures repeated at lags of 20 intervening items. The task was simply to decide whether each picture was new or had been seen before in the series. We also tested a group of 12 older adults (mean age 78 years) whose educational and social backgrounds were similar to VL's. The hit rate (saying "old" to repeated pictures) for this group was 0.97 versus VL's hit rate of 1.00, but there was a huge difference in false alarm rates (0.01 for the control group and 0.79 for VL). Especially later in the series, she claimed she had seen virtually every new picture beforehand.

The results of a structural MRI scan carried out at Sunnybrook Hospital by Dr. Sandra Black and her colleagues showed that VL had suffered tissue loss through atrophy in frontal and medial–temporal regions, with damage in the latter, predominantly in hippocampus, parahippocampal cortex, and probably also perirhinal cortex. My colleague Morgan Barense has shown that the association between medial temporal damage and difficulties of perceptual discrimination is also found in amnesic patients (Barense et al., 2012a,b), thereby advancing the case for a close relationship between memory and perception. Barense and colleagues also argue that damage to the hippocampus and parahippocampus may be associated with both perceptual and memory failures. The same argument can be applied to VL's impairments; that is, damage to her medial temporal regions resulted in losses of higher-order perceptual representations, leading her to attribute the overlap of lower-order features between present and past pictures to familiarity, especially as testing continued. Speculatively, this impairment resulted in her dramatically high false-alarm rate on our picture test and to her déjà vu experiences (or déjà vécu experiences; Moulin et al., 2005). Moulin and colleagues use the phrase déjà vécu (already lived) to make the point that the false memories experienced by VL and by similar patients they describe are not simply experiences of familiarity, but experiences of having *lived through* a comparable situation in the past. To sum up this section, the findings and analyses of Murray et al. (2017) and Barense et al. (2012a,b) strongly suggest that regions of the medial–temporal lobes have evolved to represent hierarchically organized representations of patterns and events, and that these representations serve both perceptual and memory functions. Impairments of the higher levels of the representations lead to difficulties of perceptual discrimination and also failures of memory—of which pathologically higher levels of false alarms and experiences of déjà vécu are one example.

My own thoughts about the close interactions between perception and memory stem from my interest in Treisman's theory of attention, as described in Chapters 1 and 3. In the Craik and Lockhart (1972) article we described memory as the "by-product" of perceptual and conceptual analyses, but after absorbing the messages provided by Kolers (1973) and Tulving (1983) I now take the view expressed by Murray et al. (2017) that various brain structures have evolved to both process and store information of different types. In order to stress the dynamic nature of these activities my preference is to regard the relevant structures as analyzing mechanisms whose function is to interpret incoming sensory data. When such incoming stimuli act as memory cues, the interpretive processes analyze sensory data in terms of representations stored from past experiences (Tulving's "ecphoric processes"), and the resulting brain activity may be experienced as a feeling of familiarity or as a full-blown conscious recollection of some past event. It is necessary to add that the analyzing mechanisms can also interact with *internally* generated processes guided in a top-down fashion to give rise to remembering in the absence of the relevant contextual information. So if I attempt to recollect details of a previous occasion, or if I am requested to remember some past events, I am capable of doing so. Neuroimaging studies have shown that initial encoding operations and subsequent retrieval operations are performed in the same brain regions (e.g., Danker and Anderson, 2010; Morcom, 2014; Nyberg et al., 2000; Wheeler et al., 2000). And in a 2015 review D'Esposito and Postle make the same case—perceptual and mnemonic processes are carried out by the same brain structures.

Schemas and novelty in the encoding process

I have participated in two neuroimaging studies that led to apparently different conclusions regarding the role and effectiveness of novelty in memory encoding. The first was a PET study carried out with Endel Tulving and other colleagues (Tulving et al., 1996). In this experiment, participants were first shown colored pictures to rate for pleasantness outside the scanner. In a second session, 24 hours later, they were shown the previously viewed ("old") pictures plus a set of new pictures in the PET scanner. The pictures were shown in blocks, made up of mostly old pictures or mostly new pictures; the participant's task was to keep a count of the smaller number in each block. So participants viewed old and novel pictures but did not make an overt old/new decision while in the scanner; they were given a recognition test at the conclusion of the scanning session, however. The PET results were reported in terms of the differences between blood flow patterns associated with old and new pictures; the subtraction "old minus new" was taken to represent familiarity activations, and the subtraction "new minus old" to represent novelty activations. The main result was that the two sets of activations involved different brain areas; familiarity activations were found in left and right frontal areas and posterior regions bilaterally, whereas novelty activations were observed in right medial-temporal areas and in temporal/parietal regions bilaterally. The authors stressed the importance of novelty for later memory, suggesting that "novelty is a necessary, though not a sufficient, condition for the long-term storage of information" (Tulving et al., 1996, p. 75). Although the authors stressed novelty, they also pointed out the necessity for all incoming material to be interpreted in terms of existing information.

Some 14 years later, and in a different neurotechnical era, I was involved in a functional magnetic resonance imaging (fMRI) study led by Jordan Poppenk, then a graduate student working with Morris Moscovitch, and now a faculty member at Queen's University in Kingston, Ontario. The study by Poppenk, McIntosh, Craik, and Moscovitch (2010) explored the role of past experience in the encoding phase of episodic memory. As in the previously described experiment, participants studied pictures of scenes three times before the scanning session and were then shown these pictures again along with new scenes in the scanner. In this case they were asked to either imagine an *action* in the scene presented or to associate a future *intention* with the scene. These mental acts were carried out for both repeated and novel scenes. After the scanning session, memory was tested for the mental acts associated with each test scene, both scenes that were repeated and those that were novel in the scanner. Participants identified the acts associated with repeated scenes more frequently than the acts associated with novel scenes, showing better "source memory" (i.e., memory for the relevant *action* or *intention*) for well-learned material than for novel material. The authors concluded that previous experience with material is an important factor in boosting the formation of new episodic memories. "Regions that preferentially predicted memory for novel scenes included bilateral prefrontal and temporal regions as well as left posterior parietal cortex and the left occipital lobe. Regions that preferentially predicted memory for repeated scenes included right postcentral gyrus, the left temporal pole and the right cingulate gyrus" (Poppenk et al., 2010, p. 4713).

The apparent discrepancy between novel events and well-established past learning as prime determinants of good memory shown by these two studies may depend partly on the different procedures and measurements used. The discrepancy may not actually be too troublesome, however. Novelty is a relative term; an event is typically novel against a background of expected events. Perhaps the ideal condition for good memory is presentation of a novel or unexpected event in the framework of a well-learned schema. The unexpected event will attract more attention during the encoding process and will also benefit from the schematic structure at the time of retrieval.

Processing resources and environmental support

I suggested in Chapter 7 that aging-related decrements in attention, memory, and learning could be attributed to a reduction in processing resources (see also Craik and Byrd, 1982). The construct of processing resources has also been invoked in the context of work on divided attention—encoding processes are disrupted as a consequence of resources being deployed elsewhere. But what exactly are these "processing resources"? One partial answer could be that they reflect the amount of cortical activity that can take place at any one time—this would presumably set a limit on the number of cognitive operations that can be performed. Taking a different tack, I have wondered over the years whether glucose utilization could be a candidate for the resources in question. If the rate of glycolysis (the breakdown of glucose to produce energy-carrying molecules) is limited, this would limit the amount of neural activity possible at any given time. A series of articles from Marcus Raichle's laboratory provides a useful overview of the role of aerobic glycolysis (AG) in brain function (Goyal et al., 2014, 2017; Raichle, 2010, 2015). Their discussion focuses largely on the role of AG in synapse formation, especially during child development; there is also a progressive loss of AG in the course of aging. Another interesting observation is that during resting states glucose consumption is particularly high in areas of the prefrontal cortex and in the default mode network. Whereas at present there is no direct evidence that glucose utilization underlies the cognitive construct of processing resources (apart, possibly, from the age-related decline in AG) it seems like an intriguing possibility.

The age-related decline in processing resources is normally reflected in less effective encoding operations. However (as described in Chapter 7), this age-related inefficiency can often be "repaired" by the use of environmental support. Just as with production deficiency in children, encoding can be boosted by ensuring "good" semantic processing, and retrieval can be enhanced by the provision of external cues and a recapitulation of the original encoding context. Provision of the item itself is the form of a recognition test is particularly helpful. I will illustrate the idea in the present context by presenting the results of a PET study led by my admirable colleague Cheryl Grady that compared regions of neural activation in younger and older participants (Grady et al., 1999). The experiment measured activity at encoding only but compared the encoding of words (names of objects) with pictures of objects, and additionally involved the use of three encoding strategies: Shallow processing (object size judgment), deep processing ("Is the object living or non-living?") and intentional learning. A recognition test for all encoded stimuli was conducted after completion of the scanning session; all test stimuli were words, regardless of whether they were originally presented as words or pictures. Table 9.1 shows recognition performance levels for both age groups, two types of material and encoding conditions.

Analyses of these behavioral data found main effects of material (pictures better than words), of age (young better than old), and encoding condition (learn > deep > shallow). Subsequent analyses within each material type showed a significant effect of age for word stimuli but not for pictures. That is, presentation of the names as pictures of objects "repaired" encoding in the older group to the point that their memory performance levels were equivalent to those of young adults (see also Craik and Schloerscheidt, 2011, described in Chapter 8, for a similar result).

The imaging results found three main patterns. First, pictures at encoding were associated with activity in extrastriate and medial–temporal regions, whereas word stimuli were associated with greater activity in left PFC and temporal cortices; older adults showed this pattern to a lesser degree. Second, deep encoding was differentiated from intentional learning for both pictures and words; deep encoding involved activity in left anterior PFC and hippocampus, whereas intentional encoding resulted in activity in right prefrontal, premotor and parietal

Table 9.1. Percentages of hits minus false alarms for picture and word recognition as a function of age group and type of processing during encoding (Grady et al., 1999)

Materials:	**Pictures**		**Words**	
Age groups:	**Young**	**Old**	**Young**	**Old**
Encoding condition				
Shallow	49	41	28	09
Deep	57	55	55	40
Learn	68	64	58	42

Source data from Grady CL, McIntosh AR, Rajah MN, Beig S, Craik FIM. The effects of age on the neural correlates of episodic encoding. Cereb Cortex. 1999 Dec;9(8):805–14. doi: 10.1093/cercor/9.8.805.

regions; again, this contrast was reduced in older adults. Third, deep encoding of pictures activated prefrontal and medial-temporal areas in both young and old groups. This (relatively) early study thus provided initial clues to understanding differences in memory associated with different materials (pictures vs. words), with different encoding strategies (shallow vs. deep vs. intentional learning) and with different age groups.

So one line of argument is that aging is associated with a reduction in available processing resources (as in the case of divided attention and possibly other conditions) and that this reduction results in processing that is less deep and elaborate, leading, in turn, to reduced levels of subsequent recollection. However, this age-related processing inefficiency can be repaired by the provision of greater environmental support, in the form of picture stimuli at encoding and recognition testing at retrieval in the case of the Grady et al. (1999) study. As commented in Chapter 7, it does not seem reasonable to suggest that pictures somehow provide more resources, but rather that pictures provide more support to appropriate encoding activities.

Remembering as an activity of brain

It is clear that the brain is an active organ, but Marcus Raichle (2010, 2015) has amplified and extended the point. He argues that the brain is intrinsically active as opposed to reactive, and that this intrinsic activation is the basis for organization. Studies using electroencephalography have demonstrated spontaneous electrical activity even at rest, maintaining the brain in a state of readiness to respond appropriately when needed. Raichle et al. (2001) discovered the default mode network (DMN), which is active during periods of rest but reduces activity during periods of task performance. Raichle argues that the brain should be seen as a federation of hierarchically organized hubs, and that the DMN is top of the hierarchy; its function, in concert with other networks, is to organize the brain's activities, to prepare it for external events, and predict likely occurrences on the basis of past experiences. In this sense the brain's intrinsic activity models the external world (Raichle, 2015).

Raichle makes the further point that sensory information is relatively impoverished and so must be elaborated and interpreted in terms of current knowledge. The emphasis is therefore on perception as an active interpretive process as opposed to one driven by external stimulation; a point in agreement with most current cognitive thinking. Given the evidence for the strong similarity between perceiving and remembering my view is simply that in the case of remembering, the sensory input, either incidentally or intentionally, acts as an interactive cue to guide the interpretive machinery of perception to evoke relevant past experience in addition to perceiving the current input.

My Rotman colleague Randy McIntosh is another cognitive neuroscientist who endorses an "activity" view of brain processes, and the notion of cognitive processes as a series of hierarchically organized computational modules. He suggests that the processes of learning and memory reflect the neural interactions among anatomically connected areas of the brain, and that the activity patterns of the resulting neural networks are influenced by "neural contexts." By this he means that the same activity in a specific brain region may represent different cognitive processes. "It is the relation of the activated region to other areas that determines the cognitive operation" (McIntosh, 1999, p. 525).

The further point that memory retrieval processes essentially recapitulate the perceptual processes carried out during initial encoding (Craik, 1983; Kolers, 1973) is now well established in the cognitive neuroscience literature (e.g., Nyberg et al., 2000; Danker and Anderson, 2010; Wheeler et al., 2000). A particularly nice example is provided by my Rotman Institute colleague Bradley Buchsbaum and his laboratory team using multivoxel pattern analysis (MVPA). This technique uses machine learning to build up machine representations of the distributed patterns of brain activity associated with a variety of perceptual inputs. Once established, the procedures can then be reversed so that now the machine representations are used to decode further patterns of brain activity representing either a percept or an evoked memory (Rissman and Wagner, 2012). The MVPA procedure thus mimics the idea presented in Chapter 5 that once the perceptual analytic machinery has been altered by an experienced event, the modified representation can later be used, in interaction with current incoming information, to represent some appropriate past experience. In the study by the Buchsbaum laboratory (Bone et al., 2019) participants first learned a series of colored visual images and were later asked to reimagine the images during an fMRI scanning session. MVPA revealed first that the machine learning algorithms correctly identified the patterns of neural activation associated with specific images and, second, that subjective reports of vivid imagery correlated with neural activity in early visual areas. Thus, when participants were able to reconstruct mentally a vivid perceptual image, this experience was associated with reactivation of brain areas concerned with early sensory aspects of visual perception. As pointed out by Bone et al. (2019) this result nicely corroborates the speculative suggestions of Hebb (1968), and is a good example of how neuroimaging techniques can confirm and complement predictions from cognitive/behavioral theories.

A second study from the Buchsbaum laboratory explored the effects of aging on memory reactivation (St. Laurent et al., 2014). Younger and older adults first learned and then mentally reimagined short audiovisual video sequences. MVPA analysis identified an array of visual, auditory, and spatial processing areas that supported neural activity during both perception and recollection. The specificity of reactivation patterns was reduced in older participants, corresponding to their reduced details of recollection. The authors attributed this age-related result to "dedifferentiation"—the proposal that older adults encode information less specifically—and also pointed out that the deficiency was not a function of degraded sensory processes. The experiment's use of short video sequences as opposed to static images directly illustrates how the brain deals with dynamic perceptual patterns; the cognitive experiences of perceiving and remembering are represented by corresponding patterns of dynamic neural activity.

Staresina and Wimber (2019) present an excellent overview of current studies and speculations on the neural mechanisms involved in memory recall. They endorse the general notion that retrieval processes recapitulate the abstract and perceptual processes associated with encoding, proposing that recall involves a reversal of the processing sequence that occurred during perception. In greater detail, the authors suggest that an incoming retrieval cue is first processed in the hippocampus where the cue "ignites" (nice term!) pattern completion operations in hippocampal circuits. The hippocampus then sends information to the entorhinal cortex, which in turn activates relevant areas of the cortex. The authors also suggest that whereas the cascade of processes during initial perception proceeds from specific sensory information to more abstract representations, this process is reversed during recall in that abstract conceptual information is initially prioritized over detailed perceptual information. This last point is in line with the common observation that much remembering is triggered top down by thoughts rather than by external cues. Their review also discusses details of the time progression of retrieval operations and the role of brain oscillations in the temporal orchestration of recall.

Summing up

When I first started working in cognitive psychology in the early 1960s, I felt I was witnessing cognitive and behavioral theories in their final phase—they would soon be supplanted by physiological theories and discoveries that would make psychology irrelevant. Some years later I was surprised to hear Donald Broadbent in a conference address assert that in his view the study of cognition would *not* be absorbed by neurophysiology, but rather the two areas would become more autonomous. I believe this is what has happened; cognitive theorizing and modeling have flourished over the past 50 years, and, in fact, I would say that to date cognitive concepts and findings have guided most experimentation in cognitive neuroscience. We may now be entering a new phase, however, in which cognitive ideas are still largely constructed from behavioral evidence and subjective reports, but are increasingly mapped onto brain structures and processes. The two areas of research now interact in a mutually beneficial way, and it is clear that discoveries in neuroscience not only provide a neural mechanism for cognitive concepts, but also serve both to constrain cognitive theorizing and to suggest new directions.

These points are well illustrated by the work described earlier in this chapter. The studies from Brad Buchsbaum's laboratory (and from other laboratories) have shown that encoding and retrieval processes are both represented by patterns of neural activity, and that these sets of activities are strikingly similar. In a sense, retrieval processes are perceptual processes in reverse, as suggested by Staresina and Wimber (2019). The notion that perception and memory have much in common, including common neural mechanisms, now appears to be widely accepted in the cognitive neuroscience literature (Barense et al., 2012a,b; Lee et al., 2012; Murray et al., 2017). In particular, these authors and others stress the role of the hippocampus and other medial–temporal structures in controlling both perceptual and mnemonic operations (see also Moscovitch et al., 2016; Nadel and Peterson, 2013). For these latter researchers, the hippocampus sits at the top of a processing hierarchy—an interesting contrast to the group working with Marcus Raichle, who considers the default mode network to be the seat of control (Raichle, 2015). The differences may be more apparent than real, however, as the hippocampus is generally considered to be one component of the default mode network. Additionally, the locus of control may vary as a function of the type of processing involved, with the hippocampus dominant in memory-related operations (Andrews-Hanna et al., 2014). So the notions of hierarchical representation and hierarchical control are firmly established, although details of the relevant structures and processes have still to be resolved. The concept of processing resources appears to be in a similar situation; it is a notion appealed to by cognitive experimentalists but not so much by the neuroscience community. This may be changing, however, as researchers are beginning to identify the related notion of working memory (WM) capacity with measures of brain connectivity. As an example, one recent review reported that "Several studies suggest that stronger inter-areal connectivity and increased connectivity between the frontal and parietal lobes are associated with inter-individual differences in WM capacity, and that this connectivity is strengthened by training" (Constantinidis and Klingberg, 2016, p. 446). Finally, the Craik and Lockhart construct of levels of processing has achieved the lofty status of neurological reality, at least in the sense that semantic processing yields a predictable pattern of activation in the left PFC. But why *exactly* does this activation result in such high levels of recollection? Further cognitive/neuroscience collaborations are still very much needed!

10
Final Reflections and Future Trends

In this final chapter I bring together some broad themes that run through the more specific and personally historical previous chapters. So the discussion in this chapter is more general and more speculative—essentially my current take on a number of big-picture topics, with some suggested future directions for theory and experimentation. I start by expanding on some issues arising from the levels-of-processing (LOP) ideas, go on to examine broader topics in encoding, retrieval, working memory (WM), and aging, and end up with some thoughts on very general issues such as the relations between perception and memory, and the usefulness of distinguishing a variety of different memory systems.

Levels of processing as hierarchies

My thoughts on LOP in memory were initially triggered by the work of Anne Treisman on attention (e.g., Treisman. 1964a, 1964b, 1967). She made substantial changes to Broadbent's (1958) filter theory of attention (an "early selection" model) by proposing a hierarchically arranged series of analysis for word identification, running from early sensory analyses to later analyses of meaning. As described earlier (Chapter 1), incoming verbal stimuli are all analyzed in terms of their sensory attributes, regardless of whether they are attended to or not, but are then subjected to a series of analytic tests along the lines of signal detection theory (Treisman, 1964a) running progressively from physical to semantic features. Stimuli pass a test and proceed to deeper levels of analysis as a function of both favorable bottom-up signal strength (d'), and favorable decision criteria (ß) established by top-down processes, with conscious awareness associated with the tests actually passed. It seems necessary to add that progressively more attentional resources are required for deeper analyses, unless either the signal is presented strongly (e.g., a word shouted loudly) or the relevant criteria are set favorably by a word's temporary or habitual importance (e.g., a word in context or the person's own name). Finally, Treisman showed that the "short-term storage time" of a word was doubled or tripled if it was fully identified as opposed to processed only peripherally. This last point led to suggestions embodied in the LOP framework proposed by Craik and Lockhart (1972).

Treisman's analytic hierarchy constitutes a model of attention in which selection is neither "early" (as in Broadbent's filter theory) nor "late" (following the

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full analysis of all incoming stimuli) but takes place throughout analysis, and is extremely responsive to subtle changes in context—both environmental and cognitive. By suggesting that memory is in a sense a byproduct of the same interpretive system, the LOP ideas necessarily involve attention and perception. In fact, attention, perception, comprehension, and memory are *all* seen as facets of one unified cognitive system, as I interpret the implications of Treisman's model. One further point about her scheme is that selective attention does not require a superordinate "controller" that directs or allocates attentional resources. Rather, control "emerges" from the moment-to-moment interaction of top-down and bottom-up influences. Intentions and goals will set the system to be particularly sensitive and responsive to relevant environmental events by setting the appropriate decision criteria to lenient levels. If this sounds just too passive, I should add that humans and other animals clearly act to maximize goal success by looking in specific directions and searching in likely locations. WM is an obvious further exception to this passive view of cognitive control. It is generally accepted that frontally based executive functions do provide attention to activate posterior representations and processing sequences (D'Esposito and Postle, 2015). Perhaps we can think of a general perceptual-comprehension system organized hierarchically à la Treisman acting as a semi-autonomous mechanism of selective attention, augmented by WM operations to meet specific cognitive needs. It is worth noting that Treisman's model was explicitly concerned with *language* processing, with the perception of words. The principles could be extended to cover all types of visual, auditory, and other materials, although I am not aware of any work taking this approach.

In our initial formulation of the LOP ideas (Craik and Lockhart, 1972) we proposed a relatively strict shallow-to-deep order of processing for incoming events. This one-way system was modified after considering the interactions with top-down processes, and then again in favor of a fundamental hierarchy of processing operations that allowed for recursive activities in the course of overall perception and comprehension (Lockhart and Craik, 1990; Lockhart et al., 1976; Rumelhart, 1977). That is, rather than viewing processing as moving inevitably from shallow to deep, we modified our view to think of a more temporally complex interplay in which partial bottom-up analyses can generate top-down hypotheses that bias the nominally earlier levels of analysis. Given such flexibility, the usefulness of the proposed hierarchical architecture could be questioned; indeed, one of my co-authors (Velichkovsky, 200l, 2002) suggested that the notion of a processing "heterarchy" may be more appropriate (see also Turvey et al., 1978). On balance, however, I prefer to stick with the hierarchical view in which a series of qualitatively different processing stages are closely linked and integrated. A series of experiments reported by Challis, Velichkovsky, and Craik (1996) provides empirical evidence on this point, and a thoughtful discussion of relevant issues was contributed by Anne Treisman in the book edited by Cermak and Craik (Treisman, 1979).

Other examples of processing hierarchies linked to perception, comprehension, and memory include models of autobiographical memory (e.g., Conway and Pleydell-Pearce, 2000). Such models may have the concept of "self" as the dominant organizing principle to manage competing goals and processing choices (e.g., Conway, 2005). In line with this perspective, Velichkovsky has suggested that self-referential processing occupies a commanding position in the processing hierarchy, serving to interpret and integrate the flow of experienced events and to provide the basis for their subsequent high level of recollection (Challis et al., 1996; Velichkovsky, 2001). Additionally, it may be noted that the concept of deep learning that is currently sweeping the world of artificial intelligence also uses an architecture composed of multiple levels of representation running from sensory features to deeper layers that represent commonalities and abstractions gleaned from many exposures to external stimuli and objects. A third example of hierarchical models in cognition comes from the domain of action control. In this case the initiating intention is formulated at some conceptual level, and the intention is translated into a relevant response via selective control levels. Is this simply "levels in reverse"? Almost certainly not, given that the peripheral levels are sensory organs in the case of LOP but effector organs in the case of action. The two sets of hierarchical networks presumably share some commonality at the deepest levels of understanding, implications, and interactions but diverge between central and peripheral levels (see, e.g., Broadbent, 1977).

Representations organized from specific to general

In Chapter 3 I suggested that Tulving's (1983) classification of episodic and semantic systems might be thought of as a hierarchically organized system of representational levels running from specific experienced episodes to context-free knowledge (see Figure 3.3). That is, as a continuum of specificity-generality rather than as separable memory systems. In this view I am following Katherine Nelson, who stated in connection with the organization of infant memory, "I prefer the terms *specific* and *general* to Tulving's *episodic* and *semantic* because they lack the mode and structure connotations of the latter terms" (Nelson, 1984, p. 106). She also makes the point that a specific memory need not be episodic, it could refer to the specific knowledge of where things are typically located in a kitchen. Nelson argues that infants first possess an undifferentiated knowledge system and that both specific and general representations emerge with maturation from this undifferentiated system, and also that infants probably have access initially to general rather than specific representations (see also McClelland et al., 1995, for how these ideas may be captured in a multilayered connectionist model of semantic memory).

My similar suggestion in Chapter 3 was that Tulving's ideas of memory systems could otherwise be expressed as a continuum of specificity running from highly context-dependent experiences (episodes) to progressively more context-free representations of general knowledge. One other similarity to Nelson's (1984) developmental views is the observation that older adults have easier access to the general aspects of events and abstract information. As described in Chapter 8, older adults often have difficulty retrieving *specifics*, both episodic (specific details of experienced events) and semantic (word and name finding problems, for example). This similarity between infancy and old age should probably be interpreted rather cautiously, however!

On the other hand, the retrieval problems experienced by older adults may have a similar basis to those shown by patients suffering from depression and/or post-traumatic stress disorder (PTSD; Williams et al., 2007). In this excellent review article, Williams and colleagues discuss the phenomenon of overgeneral memories and their possible underlying mechanisms. They endorse the hierarchical model of autobiographical memory proposed by Conway and Pleydell-Pearce (2000), noting that overgeneral memories typically occur in situations involving top-down, generative retrieval processes. They also invoke "description theory" (Norman and Bobrow, 1979), in which retrieval attempts generate a general description that then acts to recover new fragments of information meeting at least some of the criteria of the sought-for memory. Williams and colleagues document the points that overgeneral memories are associated with a difficulty in imagining future events and a reduction in problem-solving abilities. They also point out that such memories can occur with fatigue, and are associated with the performance of young children (Fivush and Nelson, 2004) and with elderly adults (Winthorpe and Rabbitt, 1988). With regard to mechanisms, Williams et al. (2007) suggest three major factors: First, reduced processing resources; second, capture of generative processes by irrelevant ideas or stimuli, indicating impaired inhibitory processes (Hasher and Zacks, 1979); and, third, functional avoidance of intrusive traumatic thoughts or memories. Together these factors result in truncated generative search processes. To circle back to my own theoretical concerns, the notions of reduced processing resources coupled with impaired inhibitory processes seem to provide a good account of the failure of healthy older adults to retrieve specific episodic and semantic memories. The association of overgeneral memories with fatigue also suggests a temporary reduction in cognitive control and in the availability of processing resources. One final factor in this mix is the general level of arousal and alertness shown by individuals at particular times and in particular circumstances. This possible explanatory factor has been neglected recently in my opinion, although there are some encouraging signs of its revival (e.g., Unsworth and Robison, 2017).

Some interesting questions emerge from a consideration of these previous two themes: The LOP hierarchy running from surface features to semantic concepts, and the proposed hierarchy for memory going from specific to general. Are these the same hierarchies? I would say probably not. The LOP ideas form a scheme for the analysis and interpretation of incoming information whereas the specific-general dimension deals with already established *representations* of knowledge at a variety of grain sizes. From Treisman's experiments it seems clear that deeper analyses in the LOP framework require more attentional resources to accomplish. As one example of this, older adults are less able to form implications from a text passage than are young adults (Till and Walsh, 1980); yet, as discussed earlier, older adults are also more prone to use general representations when it comes to memory. There are clearly many perspectives on how the cognitive system is organized, and I suspect that many of these are hierarchical in nature. This point is taken up again in the following section.

Steps or a ramp?

When considering hierarchies of representations (or analyzers) a question that has sometimes been posed to me by well-meaning yet skeptical colleagues is whether LOP constitutes a succession of qualitatively distinct processing stages or a continuum of depth—steps or a ramp? My admittedly evasive answer to this question is "well, both actually . . . " First, it is clear that deeper semantic processing is neither sensory nor phonological; "deeper" is not simply "more of the same thing," nor is it just another name for differences in memory "strength." My argument is that we are talking about a multidimensional theoretical space in this context. One descriptive plane through this space may be described as running from shallow to deep, and so a continuum of depth of processing, but another plane constitutes an ordered series of stages, evolving from sensory representations through intermediate steps to meaning and implication. There are many other similar hierarchies in cognitive domains. One obvious example is visual processing, running from sensory activations, through representations of lines, edges, and angles to the perception and identification of objects and their characteristics. Another is human development from infancy to adulthood; different ages are associated with qualitatively distinct cognitive stages, yet maturation and growth are also continuous (Case, 1992).

A slightly different view of the "steps vs. ramp" question comes from considering the role of perceptual information in recognition memory. Several studies have shown that recognition performance depends to some extent on the perceptual similarity of the study and test versions of an item. For example, a change in modality (Kirsner, 1974), orientation (Kolers, 1973), voice of speaker (Geiselman and Bjork, 1980), or the case (upper or lower) of the written letters comprising a word (Kirsner, 1973) between study and test all lower recognition memory performance. It therefore seems that (as argued by Paul Kolers, see Chapter 3) perceptual information does not simply act as the vehicle by which the conceptual message is delivered, but persists to influence the processing match between the initial event and its later re-presentation. To strengthen this argument, in many non-verbal cases the perceptual patterns themselves constitute the semantics or conceptual gist of the processing activity. Music and paintings are obvious examples; wine tasting and chess board settings are others. However, it is equally clear that we can recognize objects and events when they are presented in very *different* ways from one occasion to another—a spoken word can be recognized when re-presented visually, for example, and an object felt when blindfolded can be described orally and subsequently identified visually from the oral description (a thought experiment, by the way!). In order to integrate these two sets of observation it may be argued that patterns, objects, and events *are* processed in a hierarchical manner by perceptual to conceptual analyses to form perceptual to conceptual representations, and that all levels of analysis play some part in later recognition memory. If there is a complete perceptual mismatch between two presentations but some commonality at a higher level (e.g., visual-to-auditory word presentation), the item can still be recognized, although the present theoretical perspective suggests that recognition performance should benefit to the extent that successive presentations are similar. This final point gains support from brain scanning evidence showing that high levels of recollection are associated with high levels of overlap in neural processing networks between the initial and subsequent presentation (Nyberg et al., 2000).

Measuring depth of processing

One recurring criticism of the "levels" approach has been the absence of an independent measure of depth of processing; without such a measure it is all too easy to claim that better memory must reflect deeper initial processing. An immediate problem in this respect is to settle on a relevant scale and specify its units. But the whole idea of LOP is that the *qualitative* nature of encoding changes from shallow to deep—from sensory to perceptual to phonemic, lexical, semantic, and conceptual in the case of language. Clearly, many different encoding dimensions are involved. So perhaps the best one can achieve is a measure that is thought to correlate with some underlying abstract dimension, just as various tests of intelligence are said to measure "*g*" on the grounds that although they are not a direct measure of *g*, they correlate with it. One initially promising answer appeared to be processing time; deeper processing operations take longer than shallow operations (Craik and Tulving, 1975). However, this line of reasoning comes up against the point that highly familiar and well-learned events (like common words and meaningful pictures) are processed relatively rapidly; so processing time cannot be taken as a measure of depth when comparing different stimuli. We made this point in an experiment contrasting an easy semantic decision (words fitting a sentence frame) with a difficult shallow decision (consonant/vowel patterns in words); the latter task took longer to accomplish but was associated with poorer subsequent memory (Craik and Tulving, 1975, Experiment 5). Although we did not test this, my suspicion is that the amount of attentional resources necessary to perform a processing operation would act in a similar fashion; in general, deeper tasks require more attention, but this relation is modulated by learning and familiarity. However, it seems to me that both processing time and resource requirements *could* act as measures of depth when events are processed and measured along one dimension. As discussed earlier (Chapter 1) neurophysiological measures such as electroencephalogram (EEG) and functional magnetic resonance imaging may provide more definitive answers (see Galli, 2014, for a useful review).

The "process purity" of levels of representation?

One final topic when considering hierarchical views of cognitive processing concerns the "process purity" of constructs at levels above those of actual task measurements. When we constructed the alpha span measure, in which participant are presented with a short series (2–8) of common words and are asked to rearrange them mentally into their correct alphabetical order (see Chapter 8), we assumed we had developed a decent measure of WM. This assumption was based on the fact that alpha span requires the participant to hold material in mind while further stimuli are presented, and also to manipulate the items according to a complex rule (Craik et al., 2018a). However, further considerations forced me to reclassify alpha span as a measure of *verbal* WM, rather than as a measure of some abstract construct such as WM capacity (WMC; e.g., Conway et al., 2003; Kyllonen, 1996). These considerations were suggested by the findings of strong positive correlations between alpha span and both the Shipley Vocabulary Test and the North American Adult Reading Test (NAART), and also positive correlations between alpha span and digit span but much lower correlations between alpha span and measures of non-verbal spatial span (Craik et al., 2018a). Similarly, Oberauer et al. (2000) found that alpha span loaded strongly on a factor of verbal–numerical WM (0.63) but substantially less strongly, although still positively, on a spatial–figural factor (0.24). They concluded that WM is one general resource but differentiates at lower levels into separate verbal and spatial components.

In the same vein, we recently looked at the correlations of the Cattell Culture Fair Intelligence Test (Cattell, 1973) to measures of verbal and spatial ability. The Cattell Test is visual and non-verbal, and consists of logical problems using geometrical figures and patterns; it is generally regarded as providing a good measure of fluid intelligence (*Gf*), since neither the materials nor the logical operations are familiar. In two unpublished studies with Nathan Rose, Xiaojia Feng, and Ellen Bialystok we found a strong tendency for performance on the Cattell Test to correlate with measures of visuospatial WM but not with measures of verbal WM. In one experiment involving 62 young adults (university students) the results showed that Cattell did not correlate significantly with any measures of verbal WM (e.g., variants of the alpha span task using words and numbers) but did correlate significantly with measures of visuospatial WM (e.g., variants of the Corsi Blocks test, and spatial span using a visual 6 × 6 matrix). The Cattell Test correlated with performance on the Peabody Picture Vocabulary Test (PPVT), however (r = 0.40), showing that it does tap into aspects of general cognitive ability. The second experiment (described more fully in Chapter 6) involved 50 university students and found a similar pattern of results. The Cattell Test correlated with composite measures of visuospatial WM processing (spatial span and n-back using the 6 × 6 matrix) and with visuospatial ability but not with a composite measure of verbal WM (span and n-back using words). Again, Cattell correlated with general verbal ability (vocabulary and the F-A-S word generation test).

My point here is that measures of WM, such as alpha span, and even measures of fluid intelligence, such as the Cattell Test, appear to be heavily influenced by the materials used in the test (verbal materials in the case of alpha span and visuospatial materials in the case of the Cattell Test). That is, they do not appear to provide pure measures of WMC as discussed, for example, by Conway and colleagues (2003) or of fluid intelligence (e.g., Duncan, 2000). It is certainly possible that both alpha span and the Cattell Test may contribute to higher-level constructs in a processing hierarchy (Oberauer et al., 2000), but there is then the question of the ontological reality of such constructs. Are they correlates of actual neural networks, or are they more akin to Platonic ideals, existing in the minds of theorists rather than in the brains of individual persons? Conway et al. (2003) make the case for such high-level constructs having their reality based in executive functions associated with prefrontal brain processes, but in a later article (Kovacs and Conway, 2016) the authors suggest rather that the construct "*g*" is an emergent property of interactions among lower-order constructs. The construct of *g* is thus not only a useful descriptive device (and one that is *based* in the reality of lower-order structures and processes), but also one that *reflects* lower-level functions as opposed to playing some *causative* role in organizing and guiding cognitive processing.

Encoding processes

In the Craik and Lockhart (1972) article, and elsewhere, I have consistently maintained that there are no special processes of memory encoding, but that such encoding processes are nothing more than the basic processes of perception and comprehension (see also the discussion in Chapter 4). However, in a book chapter, Tulving (2001) pointed out first that various drugs impaired subsequent recall, and second that amnesic patients such as HM had essentially no episodic memory abilities, despite the fact that in both cases initial perception and comprehension appeared to be intact. In the previous discussion of this issue (Chapter 4) I conceded that some form of post-perceptual consolidation appears to be a necessary part of the encoding process, although consolidation appears to have no experiential correlates *at the cognitive level*. My reluctance to embrace the construct of consolidation, despite apparently overwhelming evidence in its favor in studies of both animals and humans (e.g., Dudai, 2004; Frankland and Bontempi, 2005; Squire et al., 2015), stems largely from the claim that the processes of consolidation continue for weeks, months, and even years after the initial learning event (e.g., Squire and Alvarez, 1995). I can see how this idea was deduced from studies in which animals learn to perform specific tasks and from observations of retrograde amnesia in brain-damaged patients, but the idea that *all* experienced events result in neural records jostling for shared space and resources in the cortex for months on end seems biologically implausible, to put it mildly. A 2019 article by Yonelinas, Ranganath, Ekstrom, and Wiltgen provides a more satisfactory account from my perspective. Their contextual binding theory proposes that ongoing events are bound to their contexts of occurrence in the hippocampus at the time of perception (at the cellular level at least), and that storage and retrieval of such episodic events are also dependent on the hippocampus. The neocortex, in comparison, deals with context-free habits and knowledge; it is the storage site for semantic memory, as opposed to episodic memory, and yields the experience of familiarity rather than recollection. This set of notions appeals to me in that *some* processes beyond initial perception and comprehension are required, and that these processes are impaired in the examples of drugs and amnesic patients, yet the further processes occur *at the time of encoding* rather than extend improbably for weeks and months. So I am happy to modify my conclusions about memory encoding; the relevant processes comprise the cognitive activities of perceiving and understanding plus the cognitively silent (but physiologically active) processes of hippocampally based contextual binding.

A second set of issues concerns the necessary roles of attention in encoding. The two primary aspects of attention in this regard are first selection, in which executive control processes play a major part, and, second, alertness or arousal, which is less specific, less controlled, and more dependent on such basic biological systems as the reticular activating system of the brain stem. Petersen and Posner (2012) describe three basic attentional brain networks whose functions are alerting, orienting, and executive control, respectively, with the latter two networks each split into two separable networks. Petersen and Posner present a sophisticated case for the reality of these five networks based principally on anatomical separation, and it seems that their functions complement each other to yield functions at the cognitive level. For example, detection of complex signal patterns requires not only high alertness, but also fine tuning of sensory and perceptual processes to match the expected signal. These latter processes clearly involve orienting and cognitive control. As further examples, effective task switching must involve alertness and executive control, and effective deep processing of complex verbal or pictorial material again involves alertness and cognitive control. Thus, cognitive functions are typically not "process pure" with respect to attentional networks, but derive their functions from several contributing networks whose functions complement each other in most cognitive tasks (Morris Goldsmith suggested this interesting point to me).

A further related point about encoding processes concerns the nature of the representations formed under conditions of divided attention (DA). My assumption has always been that such representations lack the elaborate semantic details associated with encoding under full attention (FA) and memory is correspondingly impaired. This assumption should perhaps be questioned, however, or at least explored further in light of the proposed account of consolidation by Yonelinas et al. (2019); an alternative possibility for DA effects is that DA *impairs contextual binding* of the perceived or learned items (see also Naveh-Benjamin, 2001).

As a more general point, it seems quite likely that the various ways of boosting the effects of encoding discussed in Chapter 4 (e.g., the generation, production, and self-reference effects and subject-performed tasks) all depend on the addition of further encoded features that are not spontaneously evoked in the course of straightforward learning. The most obvious cases are subject-performed tasks in which motoric information may be added to the encoded verbal information (Saltz and Donnenwerth- Nolan, 1981), and the picture superiority effect in which pictorial features are added.

The addition of extra encoded features as the way to boost the effectiveness of encoding processes was explored in an interesting article by Baddeley and Hitch (2017). Baddeley (1978) had previously criticized the LOP ideas by pointing out that levels manipulations had essentially no effect on memory for pictures. I agreed with this observation and attributed the lack of effect to the notion that pictures spontaneously evoke deep, meaningful encoded representations, so further semantic orienting tasks such as pleasantness ratings add nothing further of value. In their article, Baddeley and Hitch propose the notion of differential "affordance" (a Gibsonian term) to suggest that different types of stimuli vary in the number and manner of encoding features that can be invoked to increase the richness and elaboration of the encoding and thus on the resulting diagnosticity of the encoded record in a subsequent memory test. In their experiments Baddeley and Hitch used sets of very similar pictures (e.g., various doors and clocks) and their memory task was four-alternative forced-choice *recognition*. So diagnosticity and discriminability were key factors. When they compared the effects of LOP encoding tasks (e.g., perceptual judgments vs. pleasantness ratings) on words and such pictures, they found LOP effects on both sets of stimuli but with a greater effects on words. They therefore concluded that words "afforded" more options for extra enrichment than did the types of pictures they used—especially given that an encoded door or clock had to be recognized in a set of four very similar doors or clocks. My relieved conclusion is therefore that no great theoretical schism separates the Craik and Baddeley positions on picture memory! Our original studies were typically done using recall; strong picture superiority effects were found, and pictures were generally insensitive to LOP manipulations. Baddeley and Hitch did find small but significant effects of LOP on their pictures, but their conclusion was that, for recognition testing at least, the crucial point is the degree of discriminability or diagnosticity that can be added by any encoding manipulation, bearing in mind the similarity or otherwise of the foil items used at test.

Recent work on the interface between attention and memory tends to focus on the executive control aspects of encoding processes, but the person's general level of arousal is also clearly important. The interesting work on time-of-day effects by Lynn Hasher, Cindy May, and colleagues (e.g. Hasher et al., 1999; May et al., 1993) is a case in point. With regard to LOP effects, following the early work of Anne Treisman described in Chapter 1, my assumption has always been that for a given type of material deeper processing requires more attention, both in terms of an adequate level of arousal and in terms of effective semantic analysis requiring cognitive control.

Divided attention at retrieval: A puzzle solved?

The roles of attention in encoding processes can be studied by withdrawing attention, as described in Chapter 4. The salient results from studies of DA *at encoding* are that DA reduces subsequent memory substantially, and that memory performance trades off lawfully against reaction time (RT) in the performance of a concurrent secondary choice RT (CRT) task (Craik et al., 1996). Thus, as performance on the memory task is emphasized by instructions, memory accuracy increases as performance slows on the CRT task; good performance on one task compensates for poor performance on the other task. Interestingly, division of attention *at the time of retrieval* obeys different rules. Performance of a secondary CRT task under DA conditions has a much smaller (although statistically significant) effect on memory performance (e.g., Baddeley et al., 1984), and in this case manipulation of the relative importance of the two concurrent tasks affects speed of performing the CRT task but has no effect on the level of memory performance.

This rather puzzling result was clarified by the findings from a study in my laboratory (Craik et al., 2018b). In the encoding phase we asked participants to learn 12 pairs of verbal paired associates under FA conditions. In the retrieval task participants were again presented with word pairs, six of which were intact copies of pairs they had studied, and six were rearranged pairs made up from words they had studied but now recombined into new pairs. The task was simply to decide as rapidly as possible whether each pair was intact or rearranged. Participants' decisions on each test trial immediately brought on the next test pair, so testing continued until all 12 test pairs were presented and responded to. The secondary task was a CRT task. After practicing the recognition task and the CRT task, participants performed 12 scored trials. On four of the trials participants carried out the CRT task under FA, to provide a baseline value to compare to performance under dual task conditions. On two of the trials participants performed the recognition task under FA, and the remaining six trials were performed under dual task conditions. On two of these DA trials participants were instructed to carry out both tasks but to pay more attention to the CRT task (DA.CRT); on two they were instructed to emphasize recognition (DA.Rg); and on two they were instructed to pay equal attention to both tasks (DA.50). In all conditions participants were instructed to respond to the task (or tasks) as rapidly as possible.

The results are shown in Figure 10.1. The left-hand panel shows the proportions of correct recognition responses under FA during retrieval and also under DA conditions at retrieval with three conditions of emphasis. Performance is highest under FA, but performance under DA conditions is only slightly lower and shows no systematic effect of emphasis. The right-hand panel of Figure 10.1 shows mean response latencies for both recognition decisions and responses to the CRT task. When the CRT task was performed alone (under FA conditions) the average response time per key press was 434 msec. This latency rose to over

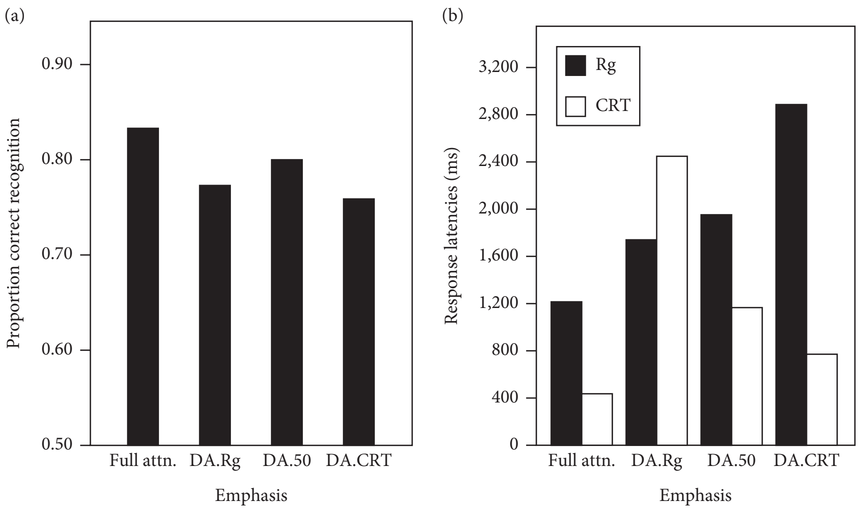

Fig. 10.1. Panel (a) shows proportions of correct recognition (Rg) responses as a function of experimental condition; full attention (FA) and three levels of emphasis during divided attention (DA) at retrieval. Emphasis was either on the Rg task, split 50/50, or on the continuous reaction time (CRT) task. Panel (b) shows response latencies for both the Rg and CRT tasks, when the tasks were performed alone (FA) and under dual-task conditions with three levels of emphasis.

2400 msec under DA.Rg conditions, and then fell progressively to DA.50 and to DA.CRT. Recognition latencies for correct decisions were just over 1200 msec when the recognition task was performed alone; latencies increased under DA conditions, and rose progressively from DA.Rg to DA.50 to DA.CRT (2877 msec). Thus, response latencies rose for recognition decisions from DA.Rg to DA.CRT, whereas CRT latencies fell progressively over the same range. The interaction between recognition latency and CRT response time over the three DA conditions was highly reliable.

The experiment thus showed that speed of performing the two concurrent tasks (recognition decisions and the CRT task) *does* trade-off between the tasks as emphasis instructions were varied. This finding appears to demonstrate that participants have a strong desire to perform as well as possible on recognition accuracy and simply defer their decision until they experience a certain level of confidence. When attention is diverted from the recognition task the decision takes longer. One way of talking about this process is in terms of Roger Ratcliff's diffusion decision model (Ratcliff et al., 2016) in which noisy information accumulates in favor of each of two alternative decisions until some preset level of acceptability for one decision is reached. The present result thus suggests that division of attention slows the accumulation of relevant evidence, a possibility that is in line with at least some similar findings in the case of aging (e.g., Thapar et al., 2003).

We had no preconceived ideas about the form of the trade-off relation between the response latencies for recognition and the CRT task, so our statistical colleague Malcom Binns attempted to fit the data with various functions. The best fit was found when Malcolm transformed the latencies to reciprocals, thereby yielding a measure of the rates of responding for the two tasks. To examine this further we chose the arbitrary time of 6 seconds, and then plotted the average numbers of CRT and recognition responses per 6-second interval for each of the two replications of the three DA emphasis conditions. Within-participant correlations between the two sets of response rates yielded an average value of $r = -0.83$ with a value of $R^2 = 0.68$, suggesting a strong linear relationship between the response rates. We also wished to assess the consistency of this linear pattern across participants, and to see if the pattern was modified by general ability. We therefore split the 24 participants into four quadrants of six participants on the basis of their overall recognition accuracy scores; the median proportions of correct responses were 0.94, 0.83, 0.72, and 0.61 (relative to chance responding = 0.50) for quadrants a, b, c, and d, respectively. The functions relating the two response rates for the four quadrants are shown in Figure 10.2. The R^2 terms for quadrants a, b, and c, were 0.95, 0.96, and 0.90, respectively, confirming excellent linear fits. However, the fit for the six participants in quadrant d was much lower ($R^2 = 0.14$), and the data clearly deviate considerably from linearity. The

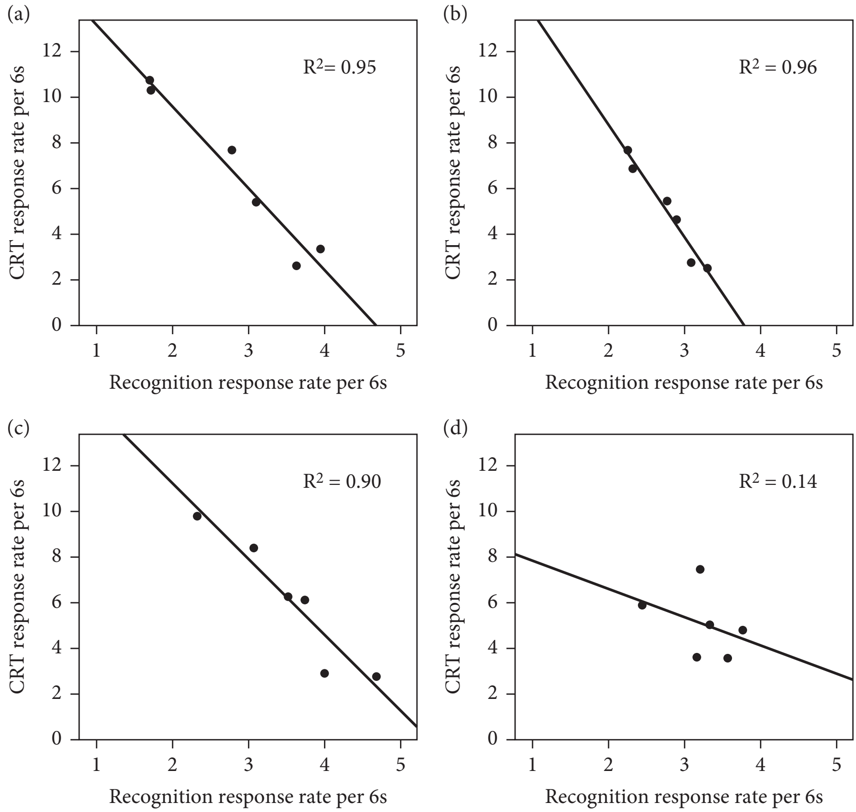

Fig. 10.2. Best-fit linear functions relating continuous reaction time (CRT) and recognition response rates per 6-second period. Each quadrant shows the data for six participants, broken down by overall recognition accuracy scores (see text).

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reasons for this deviation are unclear; speculatively, these participants may not have taken the tasks seriously, or perhaps had difficulty in managing the dual-task set-up.

The interpretation of the very lawful relationship between response rates for the majority of participants is still unclear. In practical terms, the overall data show that for every further correct recognition response within a 6-second interval, the response rate on the CRT task slows by 3.72 responses within the same interval. But it does seem plausible to suggest that both tasks rely on one common pool of processing resources (e.g., Kahneman, 1973), and that as response rates on one task are speeded by receiving more emphasis and attention, response rates on the other task are slowed accordingly. Future work must explore if this lawful trade-off between two simultaneously performed speeded tasks is a general finding or (for whatever reason) is specific to this particular combination of tasks. It would also be interesting to check if the strong relationship between two response rates typically breaks down in poorly performing participants.

I presented these findings at a meeting of the Psychonomic Society and the presentation elicited a comment from Tram Neill of SUNY Albany. His comment on the data shown in Figure 10.2 was that the pattern may not reflect memory retrieval as such, but rather competition between any two speeded tasks for the attentional resources necessary for response selection. That is, response rates for two concurrent CRT tasks might show exactly the same pattern, although no memory retrieval was involved. In a further email, Neill wrote: "It would be nice if there were some way of assessing the time course of retrieval without requiring an overt response. Maybe some ERP [event-related potential] component?" I agree with these perceptive comments, and it is interesting to speculate on the possible differences between processes accruing perceptual as opposed to memory data sufficient to select the appropriate response. Following Neill's suggestion, one approach could be to test participants under two conditions, while EEG data were recorded and analyzed by a program such as BESA (Brain Electrical Source Analysis) that tracks the spread of EEG voltage throughout the brain from stimulus onset to response production. The memory condition might consist of prior learning of a series of unrelated word pairs such as pony–table, journal–picture, etc. The later test is then to present either an intact pair (e.g., journal–picture) or a rearranged pair (e.g., journal–table) for the participant to recognize and decide as rapidly as possible whether the presented pair was intact. A corresponding "perceptual" test could be to present a word pair consisting either of two different words (e.g., journal–picture) or two identical words (e.g., journal–journal); the participant's task is to decide as rapidly as possible whether the two words are different or identical. These tests would be carried out either separately—the FA condition—or together with the CRT task described by Craik et al. (2018b)—the DA condition. The interest would then lie both in the behavioral similarity of response rate functions between the memory and perceptual variants, and also in the similarities and differences in the BESA patterns under FA and DA in the two variants. I happily bequeath this study to my successors in the field!

There are complementary cases in which encoding is *enhanced* by some manipulation. In particular, it has been known for some time that retrieval acts as a potent second encoding opportunity resulting in improved recall on a subsequent occasion (Bjork, 1975; Whitten, 1978); it has also been shown that a retrieval test is superior to a second learning opportunity—the testing effect (Karpicke and Roediger, 2008; Roediger and Karpicke, 2006).

Retrieval processes

Following the lead of Paul Kolers (1973), I suggested in an earlier publication that "retrieval processes are not seen as a 'search' for a wanted trace, but as a re-instatement of the original encoding operations" (Craik, 1983, p. 345). This view is now widely endorsed (e.g., Danker and Anderson, 2010; Morcom, 2014) and is underpinned by a substantial amount of neural evidence (e.g., D'Esposito and Postle, 2015). There is, however, some evidence that retrieval processes do *not* simply mirror encoding processes. One such set of findings led to the hemispheric encoding/retrieval asymmetry (HERA) model (Tulving et al., 1994) in which episodic *encoding* processes are associated with regions of the *left* prefrontal lobes, whereas *retrieval* processes for the same encoded events are associated with the *right* frontal lobes. However, it seems likely that these prefrontal regions act as control processes for encoding and retrieval, respectively, and that the actual representations are located in posterior regions (D'Esposito and Postle, 2015; Postle, 2006). A second source of differences between encoding and retrieval is the finding of treatments or manipulations that have strongly negative effects on encoding processes but much slighter or even no effects on retrieval processes. These manipulations include the effects of alcohol (Birnbaum et al., 1978; Söderlund et al., 2005), benzodiazepines (Curran, 1986), and division of attention (Craik et al., 1996). In the case of DA, the recent study from my laboratory described previously (Craik et al., 2018b), showed that DA *did* affect retrieval processes but that the effect was to slow retrieval latency rather than to decrease the accuracy of recall and recognition performance as happens with DA at encoding. It seems at least possible that alcohol and benzodiazepines have similar effects on retrieval, although I am unaware of studies that have demonstrated this point.

A related question concerns the *use* of extra time at retrieval under DA conditions. What is the extra time used for? Or, alternatively, what retrieval processes are slowed under DA conditions? In the earlier discussion of the Craik et al. (2018b) article, I suggested that in a recognition paradigm a diversion of resources may slow the accumulation of evidence necessary to decide whether the presented word pair was either intact or rearranged; that a limited pool of attentional resources is divided between making a correct recognition decision and making the correct CRT choice. A different account appears necessary for recall, however. In this case time is needed to reconstruct and monitor the wanted items. A related question is whether the number of words recalled under DA at retrieval is the same as under FA but simply takes longer to reach the same asymptote, or whether the asymptote is lower under DA conditions. The current evidence is that recall levels are somewhat lower under DA (Dodson and Johnson, 1996; Lozito and Mulligan, 2006; Rohrer and Pashler, 2003).

Further evidence on this issue shows that slowing of the CRT task does not appear to depend on the concurrent rate of recall. In Experiment 1 of the Craik et al. (1996) article we measured RTs on the concurrent task and also the number of words recalled in each 5-second interval of the retrieval test. Obviously, more words per 5-second interval were recalled at the beginning of the retrieval test, but RT was unaffected by the number recalled. Somewhat similarly, when retrieval instructions emphasized the relative importance of the recall task, performance on the CRT task slowed, but recall did not improve (Craik et al., 1996, 2018b). The best guess then is that greater recall *effort* results in slower RTs but does not improve recall (in these experiments at least). Similarly, even though no further words are recalled at the end of a retrieval period, concurrent RTs are not speeded. Simply *trying* to recall is sufficient to maintain RTs at a speed slower than responses when the RT task is performed by itself. Clearly more thought, analysis, and evidence are all required to clarify this issue; one factor will almost certainly be the qualitative nature of the two tasks. For example, whereas studies from my laboratory have used verbal memory tasks coupled with non-verbal stimulus–response compatible choice RT tasks, and shown minimal effects of DA at retrieval, other studies have used secondary tasks that are either more complex (e.g., Rohrer and Pashler, 2003) or are themselves verbal tasks (e.g., Fernandes and Moscovitch, 2000). These latter authors also found that the qualitative nature of the secondary task made little difference during DA at encoding—the main factor appeared to be competition for attentional resources. For DA at retrieval, however, similarity between the two tasks was necessary to cause interference with memory performance (Fernandes and Moscovitch, 2000).

Is "effort to recall" the same thing as Tulving's proposed "retrieval mode" discussed in Chapter 5? My personal view is "no"; retrieval mode appears to be a rather general state of readiness—it is "manifest as a 'tonically' maintained cognitive state" (Rugg and Wilding, 2000, p. 108). Effort to recall, however, is typically focused on some specific sought-for name or event, and may be signaled neurologically by "increased activity of whatever brain regions are engaged by the retrieval task in question" (Rugg and Wilding, 2000, p. 114). Tulving's point is that the cognitive system has to be set to interpret specific inputs as memory cues in order for them to evoke previously encoded episodes; so "synergistic ecphory" typically involves the blending of a new input with a stored record (in some sense) but under the supervision of the retrieval mode. This all seems fair enough to me, but with my previous rider that whereas retrieval mode will certainly aid recall under certain conditions, it is not a *necessary* condition for remembering. The evidence for this assertion comes from the well-documented work on involuntary memories (e.g., Berntsen, 2010) and also on the benefits of involuntary relevant cues to prospective remembering (e.g., Einstein and McDaniel, 2005). As discussed previously, the intention to carry out some action in the future seems to depend on an associative link between the stored action schema and its intended context of occurrence. When the relevant cue or context is encountered at some later time the planned action is then triggered with high probability, presumably after appropriate pre-action monitoring (Einstein and McDaniel, 2005; Goschke and Kuhl, 1996). So in my view the construct of retrieval mode is *necessary* in some conditions, helpful in other conditions, and unnecessary in situations in which cues are linked sufficiently strongly to stored episodes or preplanned actions.

In an interesting article, Douglas Hintzman (2011) develops further examples of involuntary reminding. He first takes the field of memory research to task for dwelling too exclusively on very few paradigms—e.g., paired-associate learning, free recall, and recognition memory. In a nice twist on the old story of the blind philosophers all feeling different parts of an elephant and therefore coming up with totally different descriptions of the beast's appearance, Hintzman's version is that if the blind philosophers are all feeling the elephant's tail they will be in good agreement about their observations but woefully off the mark in their descriptions of what elephants actually look like! Hintzman's contender for a phenomenon that is more central to the evolution and purpose of memory is associative reminding. He suggests that if the current awareness of an event B reminds the person of a similar event A, the implication is that A must have preceded B. If at a later time an event C reminds the person of A and B, and that A precedes B, it must mean that the A–B relation was encoded in memory. This cumulative record of being reminded of being reminded may thus lead to the construction of *recursive representations*, in which remindings are embedded in remindings; in turn such recursive representations can build up a spatiotemporal model of the individual's environment.

I must say that I like this recursive-reminding hypothesis. Hintzman goes on to suggest that such involuntary associative remindings happen to us many times each day and so constitute a plausible basis for our knowledge of the world and its interrelations. I certainly often experience remindings of previous events that seem to come out of nowhere. As an example, I was moodily doing the washing up on a recent evening in my Toronto home when I suddenly thought of a camping trip in the Scottish Highlands I had been on when I was around 18 years of age. Where did that come from? (Apart, possibly, from the subversive thought that "You know what? Camping was more fun!"). But I suspect it came from *some* associative link buried deeply under the level of conscious awareness. Mace and Unlu (2020) present an interesting and compelling account of how primed information from semantic memory influences autobiographical remembering.

At a more technical level it makes some sense that if perceiving and thinking involve the dynamic activity of specific brain networks, associative processes can complement current perceptual or ruminative processes by evoking related activations of past events. My assumption is that the current and evoked activities must share common features at some level of analysis, even though this commonality does not reach conscious awareness. Hintzman also suggest that there may have been evolutionary pressure for animals to develop recursive representations as a way of judging whether aspects of their environment are stable or have changed. This may also serve as a basis for prediction; he writes "To predict where and when something is likely to happen again, we need a record of when and how things have changed or a record of recurrence of stability if things have not changed. Recursive encodings of remindings … could be the basis of such records" (Hintzman, 2011, p. 266).

"Priming" is a phenomenon that influences retrieval, typically in an unconscious manner. It involves many qualitatively different types of representation (e.g., visual, auditory, tactile) at different levels of representation running from sensory (e.g., iconic, echoic memory) through perceptual (e.g., easier word-fragment completion following earlier exposure to the word) to conceptual (e.g., faster identification of the word "table" following earlier exposure to the word "chair"). The common principle underlying these examples appears to be activation of the relevant representation, and its biological utility is to enable faster and more effective responding when the event occurs again. In a useful review, Wiggs and Martin (1998) provide examples that demonstrate the long-lasting nature of these priming effects. The authors also endorse the suggestion that repeated events activate their neural representations with progressively less stimulus evidence. That is, priming does not involve persistently high levels of activation; rather, the first presentation sharpens the appropriate representation, stripping away irrelevancies so that the second presentation is identified faster and more efficiently.

As a final point relating to retrieval processes, Jacoby and colleagues have argued for the value of adopting a retrieval processing strategy that embodies the general characteristics of the context in which the target items were originally presented. This is source-constrained retrieval in Jacoby's terms, and represents "the self-initiated use of source information to constrain what comes to mind during retrieval" (Jacoby et al., 2005a, p. 852). This seems to me a valuable and sensible idea, although it still leaves the problem of how the relevant source information is retrieved in the first place! On reflection, it is probable that such information is embodied either in the question asked, or is otherwise accessible from the retrieval environment. In addition, general contextual sources may be more accessible than the specifics of a particular remembered episode, as suggested in a previous section of this chapter, and self-initiated activities first work to retrieve this level of representation. Three other theoretical ideas are relevant in this context; the first is Tulving's notion of retrieval mode (Tulving, 1983), although as I read it, this refers to the adoption of a very general "set to retrieve" rather than a focus on any specific internally generated cues. "Retrieval orientation" is a rather more focal notion determining the specific form of the processing that is applied to a retrieval cue. For example, orientation would differ according to whether a task required retrieval of phonological or spatial information (Rugg and Wilding, 2000).The third suggestion is that the source- constrained retrieval ideas could be integrated with Treisman's (1964a,b) model of selective attention, in which the current verbal context sets shallower selection criteria favorably for relevant incoming stimuli. In the case of source-constrained retrieval, the general source context could again set the selection criteria favorably for relevant inputs, although here the "inputs" are from stored memory records rather than from the external environment.

Working memory

To sum up my current views on what WM actually *is*, I take the view set out by D'Esposito and Postle (2015) that the experience of holding and manipulating information in conscious awareness corresponds to attention paid to a variety of activated representations. In turn, these representations may reflect very recent sensory and perceptual information, planned responses, or activated representations of knowledge stored in long-term memory (LTM). By this view there is no one coding characteristic of WM—it depends simply on what is being attended to, and that in turn is determined by the task and by the person's purposes and goals. In the same vein, the sharp capacity limitation on WM processing is attributed to the limit on the attentional resources that can be deployed at any one time; and forgetting from WM is largely a function of attention being redirected to other items or to other processing functions.

To say some more about WM codes, it seems to me that there is no need to argue for a single code at any given time. When we perceive an object we are aware of several dimensions at the same time—shape, color, texture, and function in the case of visual objects; pitch, timbre, loudness, and meaning in the case of spoken words. If WM (in some instances at least) is essentially the prolongation of the experienced sensory input by continuing to attend to the sensory–perceptual processes evoked by the external stimulus, then the momentary "WM code" will also be multidimensional. It could even involve both visual and auditory aspects—think of maintaining the image of a recent speaker's face along with the words recently uttered. This line of argument removes the need to postulate independent visual and verbal WM systems or buffers (e.g., Baddeley and Hitch, 1974; Logie, 2011; Oberauer et al., 2000), WM simply "capitalizes" on existing processing systems. Certainly, the processing systems differ considerably among themselves, and that is presumably the reason that verbal and spatial WM tasks do not correlate well (e.g., Daneman and Tardif, 1987; Oberauer et al., 2000). However, if attentional capacity (or executive function, which I take to be an extremely similar construct; see also Engle, 2018) plays a "domain-general" role in *all* WM tasks, individual differences in this ability may lie behind the generally positive correlations among WM tasks, and the common latent variable emerging from a set of WM tasks (e.g., Conway et al., 2005; Engle et al., 1999).

The somewhat novel angle suggested in the present account is that there is no need to invoke an array of discrete WM stores or processes such as verbal, visuo-spatial, phonological, articulatory, numerical, etc. All we need is the concept of a domain-free attentional resource that serves both to activate and control a wide variety of specific representations and processes. I should say that this perspective in no way invalidates the many hundreds of studies that have explored the characteristics of (e.g.) verbal and visuospatial WM. I simply suggest that the emphasis should be on determining the characteristics of the various perceptuomotor and representational systems themselves (phonological, articulatory, visuospatial, verbal, pictorial, etc.), and the range of skilled manipulative activities that can be carried out within each system.

There are some final questions about the nature of information that is not precisely in the focus of attention, but can easily be recovered and brought into that focus—for example, the items "in WM" but not in the focus of attention in Cowan's model and the information in Baddeley's episodic buffer (Baddeley, 2000). My proposal is that information in WM is held in the manner most efficient for its type; for example, verbal and numerical information is typically held in articulatory terms. In order to supplement the few items held in the focus of attention, further verbal items are retrieved from LTM but presumably then held in articulatory terms once "in WM." This suggestion corresponds to Unsworth and Engle's (2007) proposal that WM = PM + SM (where PM denotes primary memory and SM denotes secondary memory; see Chapter 3). It also suggests that semantic information is first utilized to retrieve items from SM, but words are more likely to be maintained in WM in phonemic or articulatory form. This account makes sense of the finding that individual differences in word span correlate more highly with the SM portion of free recall ($r = 0.72$) than with the PM portion ($r = 0.49$) (Craik, 1971). It also adds some clarity to the results of the experiments with Nathan Rose (Rose and Craik, 2012; Rose et al. 2015) in which we concluded that LOP effects were present only in the SM portion of WM. That is, words retrieved from SM are influenced by semantic factors (including LOP) but once in WM are more likely to be maintained in phonemic form.

Baddeley (2000) added the episodic buffer to his multicomponent model of WM in order to accommodate findings that did not sit comfortably with the existing auditory and visual stores. The buffer is described as a temporary holding mechanism of limited capacity controlled by the central executive, which can retrieve information from the buffer and so make it available to conscious awareness. Indeed, Baddeley describes the episodic buffer as the crucial interface between memory and conscious awareness. In a later article Hitch, Allen, and Baddeley (2020) link temporary storage in visual WM more explicitly to attention. They propose two types of attention. The first is "perceptual attention," which selects some subset of the visual input to create an integrated "object file"—a bound set of features that is registered in the visuo-spatial sketchpad. Once registered, the visual representation is transferred to the episodic buffer where its continued maintenance depends on the second type of attention, activation by the central executive control system. Thus, maintenance of visual information (and presumably information from other modalities also) depends on continued attention to bound features supplied by appropriate perceptual analyzers. This account seems—at the very least—pretty similar to the general account of WM described in this chapter. WM is an umbrella term describing phenomena in which perceptually processed pieces of information are held temporarily by processes of attention controlled by executive functions. The executive control processes can act simply to maintain the information in its present form or manipulate and modify the information in light of current needs and task demands. The further notion embodied in the episodic buffer concept is presumably that WM can involve attention paid to an arbitrary selection of recently presented and perceptually processed items (primed, yet still below the threshold of conscious awareness) as opposed to the activation of representations in their "home base" in LTM.

Aging

One theme emphasized throughout this book is that cognitive experiences and behaviors reflect the necessary interactions between self-initiated mental processes and processes driven or supported by the external environment (Craik, 1983, 1986). I also suggested in Chapter 7 that many age-related memory failures could not only be attributed to failures of self-initiation, but also that such deficits could be overcome by boosting the contributions offered by appropriate environmental support. Thus, age-related decrements tend to be greater in recall than in recognition (Craik and McDowd, 1987) given that contextual support is usually greater in the latter. A further anecdotal example of the same fundamental problem of aging is a difficulty in envisaging the route one is about to drive when setting out on a car trip. In my case (and those of at least some friends in their seventies and eighties) the correct branches and turns are perfectly obvious once we encounter them in the drive; the difficulty lies in a reduced ability to conjure up an image of these choice points before setting out. In this sense, GPS devices provide a kind of "electronic environmental support" to spare the effortful burden of too much self-initiated activity!

Such problems may be summed up in a sort of "proximal-distal hypothesis" of cognitive aging. That is, immediate perceptions and other aspects of the here and now give older people relatively few problems, whereas problems arise when thoughts and actions are not supported either by the current environment or by well-learned knowledge and habitual routines. This suggested age-related reversion to a greater reliance on the here and now is clearly reminiscent of Piaget's theory of infant development—but in reverse! One marked difference, however, is that, unlike infants, older adults have developed extensive batteries of conceptual knowledge and habitual skilled procedures to draw on when the current environment is inadequate (Craik and Bialystok, 2006). The reduced effectiveness of self-initiated activity in older people may also play a role in the adequacy of "source-constrained retrieval" in the elderly. The suggestion with regard to aging is that a deficiency of self-initiated processing could result in a failure to reinstate the general context of initial occurrence, and so fail to retrieve the more specific details of the original event (Jacoby et al., 2005b).

Two further related memory problems experienced by older adults are in prospective memory and memory for source (see Chapter 8). In terms of the preceding discussion my view is that age-related impairments in prospective memory are again attributable to inefficiencies in frontal functioning resulting in compromised self-initiated activities. The study by Cohen et al. (2001) described in Chapter 8 suggested that the ability to "remember to remember" is particularly impaired in older adults. Other studies (e.g., Einstein et al., 1995) have shown that as the environment provides more reminders about the prospective action—for example, event-cued tasks as opposed to time-cued asks—the age decrement is reduced. Memory for the original context or source in which information was learned or an event was experienced appears to depend on somewhat different factors, although it is again a type of memory that declines with age (McIntyre and Craik, 1987; Spencer and Raz, 1995). In this instance, the inability probably involves an encoding failure, as well as a retrieval failure, with the encoding problem reflecting an age-related inefficiency in associative binding (Naveh-Benjamin, 2000; Chalfonte and Johnson, 1996), in this case between events and their contexts of occurrence. Impairments of source memory may also involve retrieval problems, however—possibly an age-related difficulty in retrieving the less central aspects of encoded events. This topic is dealt with next.

In a previous section (and also in Chapter 8) I discussed findings related to the idea that older adults have trouble encoding and retrieving highly specific aspects of events. A difficulty with name retrieval is one obvious example, and another is the tendency to retrieve general aspects of autobiographical events rather than specific details (Winthorpe and Rabbitt, 1988). This latter tendency in various populations has been termed *over-general memory* and occurs in clinical cases of depression and PTSD (Williams et al., 2007). Both Winthorpe and Rabbitt (1988) and a later follow-up study by Phillips and Williams (2011) reported that older adults produce many such over-general memories, with their incidence related to reduced WMC (Winthorpe and Rabbitt, 1988) and to cognitive impairment assessed by the Mini–Mental State Examination (MMSE) test (Phillips and Williams, 2011). This is clearly a topic worthy of further research, with the interesting possibility that a reduction in WMC (and possibly in the effectiveness of executive functions) limits the "depth of retrieval" that a person can achieve. It seems likely that the retrieval of specific details requires more "processing power," more attentional resources, and a higher level of arousal. A further useful line of inquiry would be to check differences *within* individuals as a function of arousal and fatigue—at different times of day, for example (May et al., 1993). How consistent is the correlation between successful retrieval of specific detail and relevant measures of WM?

On memory systems

How many memory systems are there? Endel Tulving asked this rhetorical question almost 40 years ago (Tulving, 1985), and promptly answered “three”—procedural, semantic, and episodic. He associated each system with a different form of consciousness—anoetic, noetic, and autonoetic, respectively—by which he meant that humans are unaware of the operations of procedural memory and are aware of information retrieved from semantic memory, but the information is general and context-free. Humans are also aware of information retrieved from episodic memory, and in this case the memory is of personally experienced events. Tulving also suggested an evolutionary basis for these three systems, with anoetic procedural memory (or learning) arising first in relatively simple animals, noetic semantic memory in more complex animals, and autonoetic episodic memory occurring only in the most evolved animals—perhaps only in humans older than three years (Tulving, 1983). Later, Schacter and Tulving (1994) added two further systems, the perceptual representational system (PRS) and WM, a classification endorsed in a later chapter by Schacter et al. (2000), in which they added supportive evidence from neuroimaging.

Other highly influential schemes include the division into STM, LTM, and sensory memory (or presumably sensory *memories,* given the various sensory modalities of hearing, vision, touch, etc.)—the so-called “modal model” of human memory at that time (Murdock, 1967). A version of this tripartite division was elaborated by Atkinson and Shiffrin (1968) and has guided research to the present day. As discussed earlier in this volume, Waugh and Norman (1965) revived the distinction made first by William James (1890) between information currently in conscious awareness (primary memory) and secondary memory, information that we are unaware of but which can be retrieved and so brought into consciousness. It is worth noting that these proposed divisions of memory are based entirely on cognitive criteria; the stores or systems are distinguished in terms of their different capacities, encoding and retrieval characteristics, mechanisms of forgetting, and relationships to conscious awareness. Other bases of differentiation are also possible, however, appealing in some cases to brain mechanisms and evolutionary considerations.

As one influential example, Larry Squire and his collaborators suggested a taxonomy that divided memory into declarative (potentially conscious) and non-declarative or procedural (non-conscious) branches. They further nested WM, and episodic and semantic memories under the declarative heading, and priming, skill-learning, and classical conditioning under the heading of procedural memory (Squire, 1987). Squire and others (e.g., Eichenbaum, 1997; Zola and Squire, 2000) have gone on to identify brain structures and systems with this taxonomy in various animal species. In particular, they have associated the hippocampus and related medial–temporal structures with declarative memory and its constituent episodic and semantic branches. Procedural memories are associated with relevant activated perceptual, conceptual, and motor regions, including associative links between them (e.g., in the case of highly overlearned perceptual–motor sequences). Recent studies of WM are largely agreed that executive processes originating in the frontal lobes play a crucial role (e.g., Fletcher and Henson, 2001; Goldman-Rakic, 1996).

Taking a radically different approach, Murray, Wise, and Graham (2017) have published a thought-provoking book proposing a set of memory systems based on evolutionary principles. Stressing the biological and survival needs of different species in different epochs the authors propose systems ranging from the *reinforcement system* of early animals, through the *navigation memory system* of early vertebrates, the *biased-competition system* of early mammals (using past experience as a means to regulate foraging and energy retention), to systems that have evolved in primates. These latter systems include the *manual-foraging system* of early primates, *feature memory* (for visual, auditory, and other senses; the authors argue here for the integration of perception and memory), the *goal-memory system* of anthropoids, and the *social-subjective memory system* of hominins, enabling representations of self and others in the prefrontal cortex. This evolutionary view is clearly compatible with an approach based on neural systems and regions but is much larger in scope given that it includes relatively primitive learning mechanisms and involves a larger array of organisms past and present.

Much recent work in cognitive neuroscience research has focused on the various neural networks that support aspects of cognitive performance. In 1990 Posner and Petersen published a review article in which they described three major networks that contribute to processes of attention; namely, alerting, orienting, and executive control (Posner and Petersen, 1990). Some 20 years later they updated their analysis (Petersen and Posner, 2012), providing evidence that the orienting and executive control networks could each be split into two component networks. They also stressed that these attentional networks were *sources of influence* as opposed to substantive processing systems in their own right. In parallel work, Raichle and colleagues identified the default mode network (DMN; see Chapter 9) which in its active state is associated with episodic memory. More specifically, St. Jacques, Kragel, and Rubin (2011) described four networks that support memory retrieval: (1) medial prefrontal cortex, associated with self-referential processing; (2) the medial–temporal lobe network responsible for memory content; (3) the frontoparietal control network associated with strategic search; and (4) the cingulo-opercular network associated with goal maintenance. The authors stress the dynamic nature of these networks, and the point that ongoing activities of accessibility and recollection modify the connectivity between networks. They comment that "Neural networks, however, are not completely segregated from one another but contribute to cognition through the interaction of sparse connections potentially mediated by cortical hubs" (St. Jacques et al., 2011, p. 609). In a further breakdown, Ramanan (2017) describes work that suggests different networks for picture memory (the parietal network and an anterior section of the frontoparietal control network) and for autobiographical memory (regions of the DMN). This rapidly evolving research scene is apparently one in which different memory processes engage aspects of different networks as dynamic components.

What are we to make of these many varied "systems of systems"? I remember a time in the 1990s when so many new memory systems were being proposed—prospective memory, autobiographical memory, implicit memory, explicit memory, memory for faces, places, and spaces—that there was a virtual gold rush of investigators eager to stake their claim and fame on each new proposed memory construct. So much so that I recall Roger Ratcliff standing up during a memory symposium at a meeting of the Psychonomic Society to reassure the audience that in the recently published book by Schacter and Tulving, *Memory Systems 1994*, the number in the title referred to the date, not the latest tally of proposed systems! It seems clear that the different sets of systems address different levels of description of memory phenomena. Some identify different types of memory in purely cognitive terms, others address brain structures or biological functions; the value of each approach should perhaps be judged more on its usefulness to generate insightful ideas and illuminating experiments.

I have maintained through the years that the "memory systems" view of Tulving (1983) and Tulving and Schacter (1990) is an extremely useful one descriptively. Episodic and semantic memory systems are clearly different in many respects; involvement of "self" and specificity of remembered time and place in the case of episodic memory, and the retention of context-free names, facts, and ideas in semantic memory. Implicit and explicit (episodic) memory tasks show differential sensitivity to perceptual and conceptual information; the PRS system deals with sensory information of various types, and this makes it qualitatively different from say semantic memory. In addition, a memory systems view enables us to understand a wide variety of memory phenomena—e.g., why amnesic patients retain motor skills (procedural memory) but not memory for recent events (episodic memory), why errors of verbal recollection change from "acoustic errors" in short-term retention to semantic errors in long-term retention, why memory span is so limited, and many other examples.

But I also see the difficulties inherent in defining systems as self-contained entities, requiring definitions of their boundary conditions. These difficulties, involving characteristics that appeared to vary considerably across different tasks and materials, constituted the basis for arguments against the usefulness of the memory stores model (Craik and Lockhart, 1972). There are obvious differences between memory for words and memory for pictures and faces, but does each type of memory represent a different "system"? Similarly, performance on verbal WM tasks is largely independent of performance on visuospatial WM tasks (Oberauer et al., 2000), but I see no need to think of them as different WM systems. This particular problem is solved by regarding WM as attention paid to a wide variety of qualitatively different types of information (Chapter 6), an approach that focuses on a general *mechanism* underlying a variety of different cases, rather than on the defined characteristics of one hypothesized system. As another example, the sensory processes associated with vision, audition, touch, taste, and smell are clearly different from each other, but my preference is to focus on the specific characteristics of visual processing, say, rather than attempt to define the commonalities of an all-inclusive PRS system. The characteristics associated with implicit memory tasks are demonstrably different from the characteristics of episodic memory tasks (e.g., greater sensitivity to perceptual information in the former, and to conceptual information in the latter), but this difference can be accounted for more satisfactorily by focusing on the type of information required by each retrieval task, as described in Chapter 5. The early results from work on neural networks suggest that different memory tasks draw selectively on a growing number of identified networks, depending, for example, on the need for executive control, on strategic search, the involvement of a face processing network, or the involvement of "self." In general then, while applauding the usefulness of a memory systems framework for describing the cognitive characteristics of different types of memory and so organizing our further research efforts, I believe that the framework should be restricted to the descriptive level, and that it is more fruitful at this stage to focus on underlying mechanisms and their neural correlates.

Reprise

The general theme that I have proposed and promoted in this book is that remembering should be viewed as an activity of mind and brain. One caveat here is that the description "remembering," used precisely, refers only to conscious recollection, although it may also be stretched to cover feelings of familiarity in cases where the original context is not retrieved. Although instances of implicit and procedural memory do not follow this strict usage, I have broadened my use of the word remembering throughout the book to include them given that these forms of memory and learning also reflect *activities* of mind and brain. Other aspects of my personal perspective set out in the preceding chapters include the notion that remembering consists essentially of a reactivation of encoding processes and that "encoding processes" are nothing more than the mental activities involved in perceiving and understanding. I have suggested, somewhat more radically, that "memory traces" are actually analyzers, modified, sharpened, and differentiated by many previous encounters with similar events. The suggestion is that these systems of analyzers are organized hierarchically, with those involved in general, higher-order conceptual processing occupying upper positions in the hierarchy, and with lower positions occupied by analyzers capable of regenerating specific contextual details of previous occurrences. The idea that incoming sensory information is analyzed and interpreted by already existing conceptual processes is simply common sense—we understand the world in terms of what we know. The extension of this idea to remembering the specifics of previous occasions suggests only that each hierarchical system of analyzers runs from those concerned with context-free conceptual processing to those concerned with increasingly detailed and specifically contextual analyses. The further point to add about these "dynamic memory traces" is that they operate by interacting with either (or more usually both) incoming sensory data and top down influences generated by needs, desires, goals, current thoughts, and associated memories. These interactive processes conform largely to Tulving's (1983) concept of synergistic ecphory—the elicitation of memories by the interaction of current perceptual processes and pre-existing memory traces. WM is described in terms of attention paid to activated representations at various qualitative levels in long-term or secondary memory, in line with much current work in cognitive neuroscience. And, finally, age-related memory losses are attributed largely to a difficulty of "self-initiation" of appropriate encoding and retrieval operations, a difficulty stemming from reduced processing resources and inefficient cognitive control, but compensated in many circumstances by support from the external environment. As an overall summary statement, remembering *is* an activity of mind and brain!

References

Amer, T., Anderson, J. A. E, and Hasher, L. (2018). Do young adults show conceptual knowledge of previous distraction? *Memory*, *26*, 251–259.

Ames, A. (1951). Visual perception and the rotating trapezoidal window. *Psychological Monographs: General and Applied*, *65*, 1–32. doi: 10.1037/h0093600.

Anderson, C. M. B. and Craik, F. I. M. (1974). The effect of a concurrent task on recall from primary memory. *Journal of Verbal Learning and Verbal Behavior*, *13*, 107–113.

Anderson, J. R. (1974). Retrieval of propositional information from long-term memory. *Cognitive Psychology*, *6*, 451–474.

Anderson, J. R. and Bower, G. H. (1973). *Human Associative Memory*. Washington, DC: V. H. Winston & Sons.

Anderson, J. R. and Reder, L. M. (1979). An elaborative processing explanation of depth of processing. In: L. S. Cermak and F. I. M. Craik (Eds.), *Levels of Processing in Human Memory* (pp. 385–403). New York, NY: Psychology Press.

Anderson, J. R. and Reder, L. M. (1999). The fan effect: New results and new theories. *Journal of Experimental Psychology: General*, *128*, 186–197.

Andrews-Hanna, J. R., Smallwood, J., and Spreng, R. N. (2014). The default network and self-generated thought: Component processes, dynamic control, and clinical relevance. *Annals of the New York Academy of Sciences*, *1316*, 29–52.

Atkinson, R. C. and Juola, J. F. (1974). Search and decision processes in recognition memory. In D. H. Krantz, R. C. Atkinson, R. D. Luce, and P. Suppes (Eds.), *Contemporary Developments in Mathematical Psychology: I. Learning, Memory and Thinking* (pp. 242–293). San Francisco, CA: W. H. Freeman.

Atkinson, R. C. and Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. In K. W. Spence and J. T. Spence (Eds.), *The Psychology of Learning and Motivation: II*. New York, NY: Academic Press. https://doi.org/10.1016/S0079-7421(08)60422-3

Atkinson, R. C. and Shiffrin, R. M. (1971). The control of short-term memory. *Scientific American*, *225*, 82–90. https://doi.org/10.1038/scientificamerican0871-82

Ausubel, D. P. (1962). A subsumption theory of meaningful verbal learning and retention. *The Journal of General Psychology*, *66*, 213–224. doi: 10.1080/00221309.1962.9711837.

Baddeley, A. D. (1966a). Short-term memory for word sequences as a function of acoustic, semantic and formal similarity. *Quarterly Journal of Experimental Psychology*, *18*, 362–365.

Baddeley, A. D. (1966b). The influence of acoustic and semantic similarity on long-term memory for word sequences. *Quarterly Journal of Experimental Psychology*, *18*, 302–309.

Baddeley, A. D. (1978). The trouble with levels: A reexamination of Craik and Lockhart's framework for memory research. *Psychological Review*, *85*, 139–152. doi: 10.1037//0033-295x.85.3.139.

Baddeley, A. D. (1993). Working memory or working attention? In: A. D. Baddeley and L. Weiskrantz (Eds.), *Attention: Selection, Awareness, and Control: A Tribute to Donald Broadbent* (pp. 152–170). New York, NY: Clarendon Press/Oxford University Press.

Baddeley, A. D. (1996). Applying the psychology of memory to clinical problems. In D. Herrmann, C. McEvoy, C. Hertzog, et al. (Eds.), *Basic and Applied Memory Research: Theory in Context* (Vol. 1, pp. 195–220). Mahwah, NJ: Lawrence Erlbaum Associates Inc.

Baddeley, A. D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences*, *4*, 417–423.

Baddeley, A. D. (2007). *Working Memory, Thought, and Action*. New York, NY: Oxford University Press.

Baddeley, A. (2012) Working memory: Theories, models, and controversies. *Annual Review of Psychology*, *63*, 1-29.

Baddeley, A. D. and Hitch, G. J. (1974). Working memory. In: G. H. Bower (Ed.), *The Psychology of Learning and Motivation* (pp. 47–89). New York, NY: Academic Press.

Baddeley, A. D. and Hitch, G. J. (2017). Is the Levels of Processing effect language-limited? *Journal of Memory and Language*, *92*, 1–13. doi: 10.1016/j.jml.2016.05.001.

Baddeley, A. D. and Logie, R. H. (1999). Working memory: The multiple-component model. In: A. Miyake and P. Shah (Eds.), *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control* (pp. 28–61). New York, NY: Cambridge University Press. https://doi.org/10.1017/CBO9781139174909.005

Baddeley, A. D. and Warrington, E. K. (1970). Amnesia and the distinction between long- and short-term memory. *Journal of Verbal Learning & Verbal Behavior*, *9*, 176–189. doi: 10.1016/S0022-5371(70)80048-2.

Baddeley, A., Lewis, V. J., Eldridge, M., and Thomson, N. (1984). Attention and retrieval from long-term memory. *Journal of Experimental Psychology: General, 113*, 518–540.

Bahrick, H. P., Bahrick, P. O., and Wittlinger, R. P. (1975). Fifty years of memory for names and faces: A cross-sectional approach. *Journal of Experimental Psychology: General*, *104*, 54–75. http://dx.doi.org/10.1037/0096-3445.104.1.54

Baltes, P. B. and Lindenberger, U. (1988). On the range of cognitive plasticity in old age as a function of experience: 15 years of intervention research. *Behavior Therapy*, *19*, 283–300. https://doi.org/10.1016/S0005-7894(88)80003-0

Baltes, P. B., Cornelius, S. W., Spiro, A., et al. (1980). Integration versus differentiation of fluid/crystallized intelligence in old age. *Developmental Psychology*, *16*, 625–635. https://doi.org/10.1037/0012-1649.16.6.625

Baltes, P. B., Reuter-Lorenz, P. A., and Rösler, F. (Eds.) (2006). *Lifespan Development and the Brain: The Perspective of Biocultural Co-constructivism*. New York, NY: Cambridge University Press.

Barense, M. D., Ngo, J. K. W., Hung, L. H. T., and Peterson, M. A. (2012a). Interactions of memory and perception in amnesia: The figure-ground perspective. *Cerebral Cortex*, *22*, 2680–2691.

Barense M. D., Groen I. I. A., Lee A. C. H., et al. (2012b). Intact memory for irrelevant information impairs perception in amnesia. *Neuron*, *75*, 157–167.

Barrouillet, P., Bernardin, S., and Camos, V. (2004). Time constraints and resource sharing in adults' working memory spans. *Journal of Experimental Psychology: General*, *133*, 83–100. https://doi.org/10.1037/0096-3445.133.1.83

Bartlett, F. C. (1932). *Remembering: A Study in Experimental and Social Psychology*. Cambridge: Cambridge University Press.

Bartsch, L. M., Singmann, H., and Oberauer, K. (2018). The effects of refreshing and elaboration on working memory performance, and their contributions to long-term memory formation. *Memory & Cognition*, *46*, 796–808.

Benjamin, A. S. (2001). On the dual effects of repetition on false recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *27*, 941–947.

Benjamin, A. S. (2010). Representational explanations of "process" dissociations in recognition: The DRYAD theory of aging and memory judgements. *Psychological Review*, *117*, 1055–1079. doi: 10.1037/a0020810.

Berntsen, D. (2010). The unbidden past: Involuntary autobiographical memories as a basic mode of remembering. *Current Directions in Psychological Science*, *19*, 138–142. doi: 10.1177/0963721410370301.

Bertsch, S., Pesta, B. J., Wiscott, R., and McDaniel, M. A. (2007). The generation effect: A meta-analytic review. *Memory & Cognition*, *35*, 201–210.

Birnbaum, I. M., Parker, E. S., Hartley, J. T., and Noble, E. P. (1978). Alcohol and memory: Retrieval processes. *Journal of Verbal Learning & Verbal Behavior*, *17*, 325–335. https://doi.org/10.1016/S0022-5371(78)90210-4

Birren, J. E. and Schaie, K. W. (1977). *Handbook of the Psychology of Aging*. New York, NY: Van Nostrand Reinhold.

Bjork, R. A. (1975). Retrieval as a memory modifier: An interpretation of negative recency and related phenomena. In: R. L. Solso (Ed.), *Information Processing and Cognition: The Loyola Symposium* (pp. 123–144). HIllsdale, NJ: Erlbaum.

Bjork, E. L. and Bjork, R. A. (2011). Making things hard on yourself, but in a good way: Creating desirable difficulties to enhance learning. In: M. A. Gernsbacher, R. W. Pew, L. M. Hough, and J. R. Pomerantz (Eds.) and FABBS Foundation, *Psychology and the Real World: Essays Illustrating Fundamental Contributions to Society* (pp. 56–64). New York, NY: Worth Publishers.

Bone, M. B., St-Laurent, M., Dang, C., et al. (2019). Eye-movement reinstatement and neural reactivation during mental imagery. *Cerebral Cortex*, *29*, 1075–1089.

Boring, E. G. (1950). *A History of Experimental Psychology*. New York: Appleton-Century.

Botvinick, M. M. (2008). Hierarchical models of behavior and prefrontal function. *Trends in Cognitive Sciences*, *12*, 201–208.

Bouazzaoui, B., Fay, S., Taconnat, L., et al. (2013). Differential involvement of knowledge representation and executive control in episodic memory performance in young and older adults. *Canadian Journal of Experimental Psychology/Revue anadienne de psychologie expérimentale*, *67*, 100–107. doi: 10.1037/a0028517.

Bower, G. H., Clark, M. C., Lesgold, A. M., and Winzenz, D. (1969). Hierarchical retrieval schemes in recall of categorized word lists. *Journal of Verbal Learning & Verbal Behavior*, *8*, 323–343.

Bransford, J. D. and Johnson, M. K. (1972). Contextual prerequisites for understanding: Some investigations of comprehension and recall. *Journal of Verbal Learning & Verbal Behavior*, *11*, 717–726. doi: 10.1016/S0022-5371(72)80006-9.

Bransford, J. D., Barclay, J. R., and Franks, J. J. (1972). Sentence memory: A constructive versus interpretive approach. *Cognitive Psychology*, *3*, 193–209.

Bransford, J. D., Franks, J. J., Morris, C. D., and Stein, B. S. (1979). Some general constraints on learning and memory research. In: L. S. Cermak and F. I. M. Craik (Eds.), *Levels of Processing in Human Memory* (pp. 331–354). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Bransford, J. D., McCarrell, N. S., Franks, J. J., and Nitsch, K. E. (1977). Toward unexplaining memory. In: R. E. Shaw and J. D. Bransford (Eds.), *Perceiving, Acting, and Knowing: Toward an Ecological Psychology* (pp. 431–463). Hillsdale, NJ: Erlbaum

Braver, T. S. and Barch, D. M. (2002). A theory of cognitive control, aging cognition, and neuromodulation. *Neuroscience & Biobehavioral Reviews*, *26*, 809–817.

Braver, T. S. and West, R. (2008). Working memory, executive control, and aging. In F. I. M. Craik and T. A. Salthouse (Eds.), *The Handbook of Aging and Cognition* (3rd ed., pp. 311–372). New York, NY: Psychology Press.

Braver, T. S., Barch, D. M., Keys, B. A., et al. (2001). Context processing in older adults: Evidence for a theory relating cognitive control to neurobiology in healthy aging. *Journal of Experimental Psychology: General*, *130*, 746–763.

Bressler, S. L. and Kelso, J. A. (2001). Cortical coordination dynamics and cognition. *Trends in Cognitive Science*, *5*, 26–36.

Broadbent, D. E. (1958). *Perception and Communication*. Oxford: Pergamon Press.

Broadbent, D. E. (1977). Levels, hierarchies, and the locus of control. *The Quarterly Journal of Experimental Psychology*, *29*, 181–201. https://doi.org/10.1080/14640747708400596

Broadbent, D. E. and Heron, A. (1962). Effects of a subsidiary task on performance involving immediate memory by younger and older men. *British Journal of Psychology*, *53*, 189–198.

Brown, G. D. A., Neath, I., and Chater, N. (2007). A temporal ratio model of memory. *Psychological Review*, *114*, 539–576. https://doi.org/10.1037/0033-295X.114.3.539

Brown, J. (1958). Some tests of the decay theory of immediate memory. *The Quarterly Journal of Experimental Psychology*, *10*, 12–21. https://doi.org/10.1080/17470215808416249

Buchsbaum, B. R. and D'Esposito, M. (2008). The search for the phonological store: from loop to convolution. *Journal of Cognitive Neuroscience*, *20*, 762–778.

Burke, D. M. and Light, L. L. (1981). Memory and aging: The role of retrieval processes. *Psychological Bulletin*, *90*, 513–546. https://doi.org/10.1037/0033-2909.90.3.513

Butler, K. M., McDaniel, M. A., Dornburg, C. C., et al. (2004). Age differences in veridical and false recall are inevitable: The role of frontal lobe function. *Psychonomic Bulletin and Review*, *11*, 921–925.

Cabeza, R. and Dennis, N. A. (2012). Frontal lobes and aging; Deterioration and compensation. In: D. T. Stuss and R. T. Knight (Eds.), *Principles of Frontal Lobe Function* (2nd ed., pp. 628–652). New York, NY: Oxford University Press.

Cabeza, R., Grady, C. L., Nyberg, L., et al. (1997a). Age-related differences in neural activity during memory encoding and retrieval: A positron emission tomography study. *Journal of Neuroscience*, *17*, 391–400. https://doi.org/10.1523/JNEUROSCI.17-01-00391.1997

Cabeza, R., Kapur, S., Craik, F. I. M., et al. (1997b). Functional neuroanatomy of recall and recognition: A PET study of episodic memory. *Journal of Cognitive Neuroscience*, *9*, 254–265.

Cabeza, R., Nyberg, L., and Park, D. C. (Eds.) (2016). *Cognitive Neuroscience of Aging: Linking Cognitive and Cerebral Aging (Second Edition)*. New York, NY: Oxford University Press.

Campeanu, S., Craik, F. I. M., and Alain, C. (2013). Voice congruency facilitates voice recognition. *PLoS One*, *8*, 1–12.

Case, R. (1992). *The Mind's Staircase: Exploring the Conceptual Underpinnings of Children's Thought and Knowledge*. Hillsdale, NJ: Erlbaum.

Castel, A. D. (2005). Memory for grocery prices in younger and older adults: The role of schematic support. *Psychology and Aging*, *20*, 718–721. doi: 10.1037/0882-7974.20.4.718.

Castel, A. D., Benjamin, A. S., Craik, F. I. M., and Watkins, M. J. (2002). The effects of aging on selectivity and control in short-term recall. *Memory & Cognition*, *30*, 1078–1085.

Castel, A. D., McCabe, D. P., Roediger, H. L. III, and Heitman, J. L. (2007). The dark side of expertise: Domain-specific memory errors. *Psychological Science*, *18*, 3–5. https://doi.org/10.1111/j.1467-9280.2007.01838.x

Cattell, J. M. (1885). Über die zeit der Erkennung und Benennung von Schriftzeichen, Bildern und Farben [The time it takes to recognize and name letters, pictures, and colors]. *Philisophische Studien*, *2*, 635–650.

Cattell, R. B. (1973). *Manual for Measuring Intelligence with the Culture Fair Intelligence Test, Scale 2 & 3. Institute of Personality and Ability Testing*. Champaign, IL: The Psycho Center T-22.

Cermak, L. S. (1972). *Human Memory: Research and Theory*. New York, NY: Ronald Press.

Cermak, L. S. (1982). The long and short of it in amnesia. In: L. S. Cermak (Ed.), *Human Memory and Amnesia* (pp. 43–59). Hillsdale, NJ: Erlbaum.

Cermak, L. S. and Craik, F. I. M. (1979). *Levels of Processing in Human Memory*. Hillsdale, NJ: Erlbaum.

Chalfonte, B. L. and Johnson, M. K. (1996). Feature memory and binding in young and older adults. *Memory & Cognition*, *24*, 403–416. https://doi.org/10.3758/BF03200930

Challis, B. H., Velichkovsky, B. M., and Craik, F. I. M. (1996). Levels-of-Processing effects on a variety of memory tasks: New findings and theoretical implications. *Consciousness and Cognition*, *5*, 142–164. doi: 10.1006/ccog.1996.0009.

Church, B. A. and Schacter, D. L. (1994). Perceptual specificity of auditory priming: Implicit memory for voice intonation and fundamental frequency. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *20*, 521–533. https://doi.org/10.1037/0278-7393.20.3.521

Clark, A. (1999). An embodied cognitive science? *Trends in Cognitive Sciences*, *3*, 345–351. doi: 10.1016/s1364-6613(99)01361-3.

Clark, A. and Chalmers, D. (1998). The extended mind. *Analysis*, *58*, 7–19.

Clarke, R. G. B. and Morton, J. (1983). The effects of priming in visual word recognition. *Quarterly Journal of Experimental Psychology*, *35A*, 79–96.

Cofer, C. N. (1965). On some factors in the organizational characteristics of free recall. *American Psychologist*, *20*, 261–272. doi: 10.1037/h0022262.

Cohen, A. L., West, R., and Craik, F. I. M. (2001). Modulation of the prospective and retrospective components of memory for intentions in younger and older adults. *Aging, Neuropsychology, and Cognition*, *8*, 1–13.

Cohen, G. (2000). Hierarchical models in cognition: Do they have psychological reality? *European Journal of Cognitive Psychology*, *12*, 1–36. https://doi.org/10.1080/095414400382181

Cohen, R. L. (1981). On the generality of some memory laws. *Scandinavian Journal of Psychology*, *22*, 267–281.

Collins, A. M. and Loftus, E. F. (1975). A spreading-activation theory of semantic processing. *Psychological Review*, *82*, 407–428. https://doi.org/10.1037/0033-295X.82.6.407

Collins, A. M. and Quillian, M. R. (1969). Retrieval time from semantic memory. *Journal of Verbal Learning & Verbal Behavior*, *8*, 240–247. https://doi.org/10.1016/S0022-5371(69)80069-1

Conrad, R. (1963). Acoustic confusions and memory span for words. *Nature*, *197*, 1029–1030.

Conrad, R. (1964). Acoustic confusions in immediate memory. *British Journal of Psychology*, *55*, 75–84. https://doi.org/10.1111/j.2044-8295.1964.tb00899.x

Constantinidis, C. and Klingberg, T. (2016). The neuroscience of working memory capacity and training. *Nature Reviews Neuroscience*, *17*, 438–449.

Conway, A. R. A., Kane, M. J., Bunting, M. F., et al. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review*, *12*, 769–786.

Conway, A. R. A., Kane, M. J., and Engle, R. W. (2003). Working memory capacity and its relation to general intelligence. *Trends in Cognitive Sciences*, *7*, 547–552.

Conway, M. A. (2005). Memory and the self. *Journal of Memory and Language*, *53*, 594–628. https://doi.org/10.1016/j.jml.2005.08.005

Conway, M. A. and Pleydell-Pearce, C. W. (2000). The construction of autobiographical memories in the self-memory system. *Psychological Review*, *107*, 261–288. https://doi.org/10.1037/0033-295X.107.2.261

Cooper, E. H. and Pantle, A. J. (1967). The total-time hypothesis in verbal learning. *Psychological Bulletin*, *68*, 221–234. doi: 10.1037/h0025052.

Corkin, S. (2013). *Permanent Present Tense: The Unforgettable Life of the Amnesic Patient, HM*. London: Basic Books.

Cowan, N. (1999). An embedded-processes model of working memory. In: A. Miyake and P. Shah (Eds.), *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control* (pp. 62–101). New York, NY: Cambridge University Press.

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and Brain Sciences*, *24*, 87–185. doi: 10.1017/S0140525X01003922.

Cowan, N. (2005). Working-memory capacity limits in a theoretical context. In: C. Izawa and N. Ohta (Eds.), *Human Learning and Memory: Advances in Theory and Application: The 4th Tsukuba International Conference on Memory* (pp. 155–175). Hillsdale, NJ: Lawrence Erlbaum Associates

Cowan, N. (2008). What are the differences between long-term, short-term, and working memory? *Progress in Brain Research Essence of Memory*, *169*, 323–338. doi: 10.1016/s0079-6123(07)00020-9.

Cowan, N. (2016). *Working Memory Capacity*. New York: Routledge.

Cox, S. R., Ritchie, S. J., Tucker-Drob, E. M., et al. (2016). Ageing and brain white matter structure in 3, 513 UK Biobank participants. *Nature Communications*, *7*, 13629. https://doi.org/10.1038/ncomms13629

Craik, F. I. M. (1965). The nature of the age decrement in dichotic listening tasks. *Quarterly Journal of Experimental Psychology*, *17*, 227–240.

Craik, F. I. M. (1968a). Types of error in free recall. *Psychonomic Science*, *10*, 353–354

Craik, F. I. M. (1968b). Two components in free recall. *Journal of Verbal Learning & Verbal Behavior*, *7*, 996–1004. http://dx.doi.org/10.1016/S0022-5371(68)80058-1

Craik, F. I. M. (1970). The fate of primary memory items in free recall. *Journal of Verbal Learning and Verbal Behavior*, *9*, 143–148.

Craik, F. I. M. (1971). Primary memory. *British Medical Bulletin*, *27*(3), 232–236. doi: 10.1093/oxfordjournals.bmb.a070859

Craik, F. I. M. (1977a). Age differences in human memory. In: J. E. Birren and K. W. Schaie (Eds.), *Handbook of the Psychology of Aging* (pp. 384–420). New York, NY: Van Nostrand Reinhold.

Craik, F. I. M. (1977b). Depth of processing in recall and recognition. In: S. Dornic (Ed.), *Attention and Performance VI* (pp. 279-297). Hillsdale, NJ.: LEA.

Craik, F. I. M. (1979). Levels of processing: Overview and closing comments. In: L. S. Cermak and F. I. M. Craik (Eds.), *Levels of processing in human memory* (pp. 447-461). Hillsdale, NJ: Erlbaum.

Craik, F. I. M. (1982). Selective changes in encoding as a function of reduced processing capacity. In: F. Klix, J. Hoffman, and E. Van der Meer (Eds.), *Cognitive Research in Psychology* (pp. 152-161). Berlin: DVW.

Craik, F. I. M. (1983). On the transfer of information from temporary to permanent memory. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *302*, 341–359. doi: 10.1098/rstb.1983.0059.

Craik, F. I. M. (1986). A functional account of age differences in memory. In: F. Klix and H. Hagendorf (Eds.), *Human Memory and Cognitive Capabilities* (pp. 409–422). Amsterdam: North-Holland.

Craik, F. I. M. (1991). On the specificity of procedural memory. In: W. Kessen, A. Ortony, and F. I. M. Craik (Eds.), *Memories, Thoughts, and Emotions* (pp. 183–197). Hillsdale, NJ: Erlbaum

Craik, F. I. M. (1999). Levels of encoding and retrieval. In: B. H. Challis and B. M. Velichkovsky (Eds.), *Stratification in Cognition and Consciousness* (pp. 97–104). Amsterdam: John Benjamins.

Craik, F. I. M. (2002). Levels of processing: Past, present . . . and future? *Memory*, *10*, 305–318.

Craik, F. I. M. (2006). Distinctiveness and memory: Comments and a point of view. In: R. R. Hunt and J. B. Worthen (Eds.), *Distinctiveness and Memory* (pp. 425–442). New York, NY: Oxford University Press.

Craik, F. I. M. (2007). Encoding: A cognitive perspective. In: H. L. Roediger III, Y. Dudai, and S. M. Fitzpatrick (Eds.), *Science of Memory: Concepts* (pp. 129–135). New York, NY: Oxford University Press.

Craik, F. I. M., Barense, M. B., Rathbone, C. J., et al. (2014). VL: A further case of erroneous recollection. *Neuropsychologia*, *56*, 367–380.

Craik, F. I. M. and Bialystok, E. (2006). Cognition through the lifespan: mechanisms of change. *Trends in Cognitive Sciences*, *10*, 131–138.

Craik, F. I. M. and Birtwistle, J. (1971). Proactive inhibition in free recall. *Journal of Experimental Psychology*, *91*, 120–123.

Craik, F. I. M. and Bosman, E. A. (1992). Age-related changes in memory and learning. In: H. Bouma and J. A. M. Graafmans (Eds.), *Gerontechnology* (pp. 79–92). Amsterdam: IOS Press.

Craik, F. I. M. and Byrd, M. (1982). Aging and cognitive deficits: The role of attentional resources. In: F. I. M. Craik and S. E. Trehub (Eds.), *Aging and Cognitive Processes* (pp. 191–211), New York, NY: Plenum.

Craik, F. I. M. and Grady, C. L. (2002). Aging, memory, and frontal lobe functioning. In: D. T. Stuss and R. T. Knight (Eds.), *Principles of Frontal Lobe Function* (pp. 528–540). New York, NY: Oxford University Press.

Craik, F. I. M. and Jennings, J. J. (1992). Human memory. In: F. I. M. Craik and T. A. Salthouse (Eds.), *The Handbook of Aging and Cognition* (pp. 51–110), Hillsdale, NJ: Erlbaum.

Craik, F. I. M. and Kerr, S. (1996). Prospective memory, aging and lapses of intention. In: M. Brandimonte, G. O., Einstein, and M. A., McDaniel (Eds.) *Prospective Memory: Theory and Applications* (pp. 227–237), Mahwah, NJ: Erlbaum.

Craik, F. I. M. and Kester, J. D. (2000). Divided attention and memory: Impairment of processing or consolidation? In: E. Tulving (Ed.), *Memory, Consciousness, and the Brain: The Tallinn Conference* (pp. 38–51). New York, NY: Psychology Press.

Craik, F. I. M. and Kirsner, K. (1974). The effect of speaker's voice on word recognition. *Quarterly Journal of Experimental Psychology*, *26*, 274–284.

Craik, F. I. M. and Levy, B. A. (1970). Semantic and acoustic information in primary memory. *Journal of Experimental Psychology*, *86*, 77–82.

Craik, F. I. M. and Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior*, *11*, 671–684. doi: 10.1016/s0022-5371(72)80001-x.

Craik, F. I. M. and Lockhart, R. S. (2008). Levels of processing and Zinchenko's approach to memory research. *Journal of Russian & East European Psychology*, *46*, 52–60.

Craik, F. I. M. and McDowd, J. M. (1987). Age differences in recall and recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *13*, 474–479.

Craik, F. I. M. and Rabinowitz, J. C. (1984). Age differences in the acquisition and use of verbal information. In: H. Bouma and D. G. Bouwhuis (Eds.), *Attention and Performance X* (pp. 471–499). London: Erlbaum.

Craik, F. I. M. and Schloerscheidt, A. M. (2011). Age-related differences in recognition memory: Effects of materials and context change. *Psychology and Aging*, *26*, 671–677.

Craik, F. I. M. and Simon, E. (1980). Age differences in memory: The roles of attention and depth of processing. In: L. Poon., J. L. Fozard, L. S. Cermak, et al. (Eds.), *New Directions in Memory and Aging* (pp. 95–112). Hillsdale, NJ: Lawrence Erlbaum Associates.

Craik, F. I. M. and Tulving, E. (1975). Depth of processing and the retention of words in episodic memory. *Journal of Experimental Psychology: General*, *104*, 268–294. doi: 10.1037//0096-3445.104.3.268.

Craik, F. I. M. and Watkins, M. J. (1973). The role of rehearsal in short-term memory. *Journal of Verbal Learning and Verbal Behavior*, *12*, 599–607. doi: 10.1016/s0022-5371(73)80039-8.

Craik, F. I. M., Bialystok, E., Gillingham, S., and Stuss, D. T. (2018a). Alpha Span: a measure of working memory. *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale*, *72*, 141–152.

Craik, F. I. M., Byrd, M., and Swanson, J. M. (1987). Patterns of memory loss in three elderly samples. *Psychology and Aging*, *2*, 79–86.

Craik, F. I. M., Govoni, R., Naveh-Benjamin, M., and Anderson, N. D. (1996). The effects of divided attention on encoding and retrieval processes in human memory. *Journal of Experimental Psychology: General*, *125*, 159–180.

Craik, F. I. M., Eftekhari, E., and Binns, M. A. (2018b). Effects of divided attention at encoding and retrieval: Further data. *Memory & Cognition*, *46*, 1263–1277. https://doi.org/10.3758/s13421-018-0835-3

Craik, F. I. M., Luo, L., and Sakuta, Y. (2010). Effects of aging and divided attention on memory for items and their contexts. *Psychology and Aging*, *25*, 968–979.

Craik, F. I. M., Morris, R. G., and Gick, M. L. (1990a). Adult age differences in working memory. In: G. Vallar and T. Shallice (Eds.), *Neuropsychological Impairments of Short Term Memory* (pp. 247–267). Cambridge: Cambridge University Press.

Craik, F. I. M., Morris, L. W., Morris, R. G., and Loewen, E. R. (1990b). Relations between source amnesia and frontal lobe functioning in a normal elderly sample. *Psychology and Aging*, *5*, 148–151.

Craik, F. I. M., Moscovitch, M., and McDowd, J. M. (1994). Contributions of surface and conceptual information to performance on implicit and explicit memory tasks. *Journal of Experimental Psychology: Learning, Memory and Cognition, 20*, 864–875.

Craik, F. I. M., Moroz, T. M., Moscovitch, M., Stuss, D. T., Winocur, G. W., Tulving, E. and Kapur, S. (1999). In search of the self: A positron emission tomography study. *Psychological Science*, *10*, 27-35.

Crowder, R. G. (1993). Systems and principles in memory theory: Another critique of pure memory. In: A. Collins, S. Gathercole, Martin A. Conway, and P. E. Morris (eds.), *Theories of Memory* (pp. 139–161). Hillsdale, NJ: Erlbaum.

Crowder, R. G. and Morton, J. (1969). Precategorical acoustic storage (PAS). *Perception & Psychophysics*, *5*, 365–373. https://doi.org/10.3758/BF03210660

Curran, H. V. (1986). Tranquillising memories: A review of the effects of benzodiazepines on human memory. *Biological Psychology*, *23*, 179–213. https://doi.org/10.1016/0301-0511(86)90081-5

Curran, H. V. (1991). Benzodiazepines, memory and mood: a review. *Psychopharmacology*, *105*, 1–8.

Danckert, S. L. and Craik, F. I. M. (2013). Does aging affect recall more than recognition memory? *Psychology and Aging*, *28*, 902–909.

Daneman, M., and Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning & Verbal Behavior*, *19*, 450–466.

Daneman, M. and Tardif, T. (1987). Working memory and reading skill re-examined. In: M. Coltheart (Ed.), *Attention and Performance XII* (pp. 491–508). Hillsdale, NJ: Erlbaum.

Danker, J. F. and Anderson, J. R. (2010). The ghosts of brain states past: Remembering reactivates the brain regions engaged during encoding. *Psychological Bulletin*, *136*, 87–102. doi: 10.1037/a0017937.

Davidson, D. (2006). Assessing distinctiveness: Measures of item-specific and relational processing. In: R. R. Hunt and J. B. Worthen (Eds.), *Distinctiveness and Memory* (pp. 109–133). New York, NY: Oxford University Press.

Dennis, N. A. and Cabeza, R. (2008). Neuroimaging of healthy cognitive aging. In: F. I. M. Craik and T. A. Salthouse (Eds.), *The Handbook of Aging and Cognition* (pp. 1–54). New York, NY: Psychology Press.

Denny, B. T., Kober, H., Wager, T. D., and Ochsner, K. N. (2012). A meta-analysis of functional neuroimaging studies of self-and other judgments reveals a spatial gradient for mentalizing in medial prefrontal cortex. *Journal of cognitive Neuroscience*, *24*, 1742–1752.

D'Esposito, M. and Postle, B. R. (2015). The cognitive neuroscience of working memory. *Annual Review of Psychology*, *66*, 115–142.

Deutsch, J. A. and Deutsch, D. (1963). Attention: Some theoretical considerations. *Psychological Review*, *70*, 51–60. doi: 10.1037/h0042712.

Diamond, A. (2002). Normal development of prefrontal cortex from birth to young adulthood: Cognitive functions, anatomy, and biochemistry. In: D. T. Stuss and R. T. Knight (Eds.), *Principles of Frontal Lobe Function* (pp. 466–503). New York, NY: Oxford University Press.

Dixon, P. and Shedden, J. M. (1993). On the nature of the span of apprehension. *Psychological Research*, *55*, 29–39. https://doi.org/10.1007/BF00419891

Dodson, C. S. and Johnson, M. K. (1996). Some problems with the process-dissociation approach to memory. *Journal of Experimental Psychology: General*, *125*, 181–194. https://doi.org/10.1037/0096-3445.125.2.181

Dodson, C. S. and Schacter, D. L. (2001). "If I had said it I would have remembered it": Reducing false memories with a distinctiveness heuristic. *Psychonomic Bulletin & Review*, *8*, 155–161.

Dudai, Y. (2004). The neurobiology of consolidations, or, how stable is the engram? *Annual Review of Psychology*, *55*, 51–86.

Duncan, J. (1995). Attention, intelligence, and the frontal lobes. In: M. S. Gazzaniga (Ed.), *The Cognitive Neurosciences* (pp. 721–733). Cambridge, MA: MIT Press.

Duncan, J., Seitz, R. J., Kolodny, J., et al. (2000). A neural basis for general intelligence. *Science*, *289*, 457-460.

Ebbinghaus, H. (1885/1964). *Memory: A Contribution to Experimental Psychology*. New York, NY: Dover.

Eichenbaum, H. (1997). Declarative memory: Insights from cognitive neurobiology. *Annual Review of Psychology*, *48*, 547–572. https://doi.org/10.1146/annurev.psych.48.1.547

Einstein, G. O. and McDaniel, M. A. (1990). Normal aging and prospective memory. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *16*, 717–726.

Einstein, G. O. and McDaniel, M. A. (1996). Retrieval processes in prospective memory: Theoretical approaches and some new empirical findings. In: M. Brandimonte, G. O. Einstein, and M. A. McDaniel (Eds.), *Prospective Memory: Theory and Applications* (pp. 115–141). Mahwah, NJ: Lawrence Erlbaum Associates Publishers.

Einstein, G. O. and McDaniel, M. A. (2005). Prospective memory: Multiple retrieval processes. *Current Directions in Psychological Science*, *14*, 286–290. doi: 10.1111/j.0963-7214.2005.00382.x

Einstein, G. O., McDaniel, M. A., Manzi, M., et al. (2000). Prospective memory and aging: Forgetting intentions over short delays. *Psychology and Aging*, *15*, 671–683. https://doi.org/10.1037/0882-7974.15.4.671

Einstein, G. O., McDaniel, M. A., Richardson, S. L., et al. (1995). Aging and prospective memory: Examining the influences of self-initiated retrieval processes. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *21*, 996–1007.

Einstein, G. O., McDaniel, M. A., Smith, R., and Shaw, P. (1998). Habitual prospective memory and aging: Remembering instructions and forgetting actions. *Psychological Science*, *9*, 284–288. https://doi.org/10.1111/1467-9280.00056

Engel, A. K., Maye, A., Kurthen, M., and König, P. (2013). Where's the Action? The pragmatic turn in cognitive science. *Trends in Cognitive Science*, *17*: 202–209.

Engelkamp, J. and Cohen, R. L. (1991). Current issues in memory of action events. *Psychological Research*, *53*, 175–182.

Engelkamp, J. and Zimmer, H. D. (1984). Motor programme information as a separable memory unit. *Psychological Research*, *46*, 283–299.

Engle, R. W. (2002). Working memory capacity as executive attention. *Current Directions in Psychological Science*, *11*, 19–23. doi: 10.1111/1467-8721.00160.

Engle, R. W. (2018). Working memory and executive attention: A revisit. *Perspectives on Psychological Science*, *13*, 190–193. https://doi.org/10.1177/1745691617720478

Engle, R. W., Tuholski, S. W., Laughlin, J. E., and Conway, A. R. A. (1999). Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General*, *128*, 309–331. https://doi.org/10.1037/0096-3445.128.3.309

Eysenck, M. W. (1978). Levels of processing: A critique. *British Journal of Psychology*, *69*, 157–169. doi: 10.1111/j.2044-8295.1978.tb01643.x.

Fernandes, M. A. and Moscovitch, M. (2000). Divided attention and memory: Evidence of substantial interference effects at retrieval and encoding. *Journal of Experimental Psychology: General*, *129*, 155–176. https://doi.org/10.1037/0096-3445.129.2.155

Fisher, R. P. and Craik, F. I. M. (1977). The interaction between encoding and retrieval operations in cued recall. *Journal of Experimental Psychology: Human Learning and Memory*, *3*, 701–711.

Fivush, R. and Nelson, K. (2004). Culture and language in the emergence of autobiographical memory. *Psychological Science*, *15*, 573–577.

Flavell, J. H., Beach, D. R., and Chinsky, J. M. (1966). Spontaneous verbal rehearsal in a memory task as a function of age. *Child Development*, *37*, 283–299. doi: 10.2307/1126804.

Fletcher, P. C. and Henson, R. (2001). Frontal lobes and human memory: Insights from functional neuroimaging. *Brain*, *124*, 849–881.

Floden, D., Stuss, D. T., and Craik, F. I. M. (2000). Age differences in performance on two versions of the Brown-Peterson task. *Aging, Neuropsychology, and Cognition*, *7*, 245–259.

Forrin, N. D, Macleod, C. M., and Ozubko, J. D. (2012). Widening the boundaries of the production effect. *Memory & Cognition*, *40*, 1046–1055. doi: 10.3758/s13421-012-0210-8.

Frankland, P. W. and Bontempi, B. (2005). The organization of recent and remote memories. *Nature Reviews Neuroscience*, *6*, 119–130.

Franks, J. J., Bilbrey, C. W., Lien, K. G., and McNamara, T. P. (2000). Transfer-appropriate processing (TAP) and repetition priming. *Memory & Cognition*, *28*, 1140–1151.

Fukuda, K., Vogel, E. K., Mayr, U., and Awh, E. (2010). Quantity, not quality: The relationship between fluid intelligence and working memory capacity. *Psychonomic Bulletin and Review*, *17*, 673–679.

Fuster, J. M. (2002). Physiology of executive functions: The perception-action cycle. In: D. T. Stuss and R. T. Knight (Eds.), *Principles of Frontal Lobe Function* (pp. 96–108). New York, NY: Oxford University Press. https://doi.org/10.1093/acprof:oso/9780195134971.003.0006

Galli, G. (2014). What makes deeply encoded items memorable? Insights into the levels of processing framework from neuroimaging and neuromodulation. *Frontiers in Psychiatry*, *5*, 61.

Gardiner, J. M. (1988). Generation and priming effects in word-fragment completion. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *14*, 495–501. doi: 10.1037/0278-7393.14.3.495.

Gardiner, J. M. and Richardson-Klavehn, A. (2000). Remembering and knowing. In: E. Tulving and F. I. M. Craik (Eds.), *The Oxford Handbook of Memory* (pp. 229–244). New York, NY: Oxford University Press.

Gardiner, J. M., Craik, F. I., and Birtwistle, J. (1972). Retrieval cues and release from proactive inhibition. *Journal of Verbal Learning & Verbal Behavior*, *11*, 778–783. https://doi.org/10.1016/S0022-5371(72)80012-4

Gardiner, J. M., Craik, F. I. M., and Bleasdale, F. A. (1973). Retrieval difficulty and subsequent recall. *Memory and Cognition*, *1*, 213–216.

Gathercole, S. E. and Conway, M. A. (1988). Exploring long-term modality effects: Vocalization leads to best retention. *Memory & Cognition*, *16*, 110–119.

Gazzaley, A. (2013). The impact of interference on working memory and long-term memory in aging. *Journal of Psychophysiology*, *27*(*Suppl. 1*), 22–23.

Geiselman, R. E. and Bjork, R. A. (1980). Primary versus secondary rehearsal in imagined voices: Differential effects on recognition. *Cognitive Psychology*, *12*, 188–205.

Gilboa, A. and Moscovitch, M. (2017). Ventromedial prefrontal cortex generates pre-stimulus theta coherence desynchronization: A schema instantiation hypothesis. *Cortex*, *87*. 10.1016/j.cortex.2016.10.008.

Glisky, E. L. and Rabinowitz, J. C. (1985). Enhancing the generation effect through repetition of operations. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *11*, 193–205.

Goldinger, S. D. (1996). Words and voices: Episodic traces in spoken word identification and recognition memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*, 1166–1183. https://doi.org/10.1037/0278-7393.22.5.1166

Goldman-Rakic, P. S. (1996). The prefrontal landscape: implications of functional architecture for understanding human mentation and the central executive. *Philosophical Transactions of the Royal Society of London*, *351*, 1445–1453.

Gollwitzer, P. M. and Brandstätter, V. (1997). Implementation intentions and effective goal pursuit. *Journal of Personality and Social Psychology*, *73*, 186–199.

Gopie, N., Craik, F. I. M., and Hasher, L. (2011). A double dissociation of implicit and explicit memory in younger and older adults. *Psychological Science*, *22*, 634–640.

Gorbach, T., Pudas, S., Lundquist, A., et al. (2017). Longitudinal association between hippocampus atrophy and episodic-memory decline, *Neurobiology of aging*, *51*, 167–176.

Goschke, T. and Kuhl, J. (1996). Remembering what to do: Explicit and implicit memory for intentions. In: M. Brandimonte, G. O. Einstein, and M. A. McDaniel (Eds.), *Prospective Memory: Theory and Application* (pp. 53–91). Mahwah, NJ: Erlbaum.

Goyal, M. S., Hawrylycz, M., Miller, J. A., et al. (2014). Aerobic glycolysis in the human brain is associated with development and neotenous gene expression. *Cell Metabolism*, *19*, 49–57.

Goyal, M. S., Vlassenko, A. G., Blazey, T. M., et al. (2017). Loss of brain aerobic glycolysis in normal human aging. *Cell Metabolism*, *26*, 353–360.

Grady, C. L., McIntosh, A. R., Horwitz, B., et al. (1995). Age-related reductions in human recognition memory due to impaired encoding. *Science*, *269*, 218–221. doi: 10.1126/science.7618082.

Grady, C. L., McIntosh, A. R., Rajah, M. N., et al. (1999). The effects of age on the neural correlates of episodic memory. *Cerebral Cortex*, *9*, 805–814.

Graf, P. and Mandler, G. (1984). Activation makes words more accessible, but not necessarily more retrievable. *Journal of Verbal Learning and Verbal Behavior*, *23*, 553–568.

Graf, P. and Ryan, L. (1990). Transfer-appropriate processing for implicit and explicit memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*, 978–992.

Gray, J. A. and Wedderburn, A. A. (1960). Grouping strategies with simultaneous stimuli. *Quarterly Journal of Experimental Psychology*, *12*, 180–184. doi: 10.1080/17470216008416722.

Greene, N. R. and Naveh-Benjamin, M. (2020). A specificity principle of memory: Evidence from aging and associative memory. *Psychological Science*, *31*, 316–331.

Greene, J. D. W., Baddeley, A. D., and Hodges, J. R. (1996). Analysis of the episodic memory deficit in early Alzheimer's disease: Evidence from the doors and people test. *Neuropsychologia*, *34*, 537–551. https://doi.org/10.1016/0028-3932(95)00151-4.

Greene, R. L. (1987). Effects of maintenance rehearsal on human memory. *Psychological Bulletin*, *102*, 403–413. doi: 10.1037//0033-2909.102.3.403.

Greene, R. L. (1989). Spacing effects in memory: Evidence for a two-process account. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *15*, 371–377.

Gregory, R. L. (1974). *Concepts and Mechanisms of Perception*. London: Duckworth.

Gyurkovics, M., Balota, D. A., and Jackson, J. D. (2018). Mind-wandering in healthy aging and early stage Alzheimer's disease. *Neuropsychology*, *32*, 89–101. doi: 10.1037/neu0000385.

Halamish, V., Goldsmith, M., and Jacoby, L. L. (2012). Source-constrained recall: Front-end and back-end control of retrieval quality. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *38*, 1–15. https://doi.org/10.1037/a0025053

Hall, N. M., Gjedde, A., and Kupers, R. (2008). Neural mechanisms of voluntary and involuntary recall: A PET study. *Behavioral Brain Research*, *186*, 261–272.

Hall, S. A., Rubin, D. C., Miles, A., et al. (2014). The neural basis of involuntary episodic memories. *Journal of Cognitive Neuroscience*, *26*, 2385–2399. doi: 10.1162/jocn_a_00633.

Hamani, C., McAndrews, M. P., Cohn, M., et al. (2008). Memory enhancement induced by hypothalamic/fornix deep brain stimulation. *Annals of Neurology*, *63*, 119–123. doi: 10.1002/ana.21295.

Harris, J. E. and Wilkins A. J. (1982). Remembering to do things: A theoretical framework and an illustrative experiment. *Human Learning*, *1*, 123–136.

Hasher, L. and Zacks, R. T. (1979). Automatic and effortful processes in memory. *Journal of Experimental Psychology: General*, *108*, 356–388. https://doi.org/10.1037/0096-3445.108.3.356

Hasher, L. and Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. *Psychology of Learning and Motivation*, *22*, 193–225. doi: 10.1016/S0079-7421(08)60041-9.

Hasher, L., Zacks, R. T., and May, C. P. (1999). Inhibitory control, circadian arousal, and age. In: D. Gopher and A. Koriat (Eds.), *Attention and Performance XVII: Cognitive Regulation of Performance: Interaction of Theory and Application* (pp. 653–675). Cambridge, MA: MIT Press.

Hasson, U., Chen, J., and Honey, C. J. (2015). Hierarchical process memory: memory as an integral component of information processing. *Trends in Cognitive Science*, *19*: 304–313. doi: 10.1016/j.tics.2015.04.006.

Hay, J. F. and Jacoby, L. L. (1996). Separating habit and recollection: Memory slips, process dissociations, and probability matching. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*, 1323–1335. https://doi.org/10.1037/0278-7393.22.6.1323

Hay, J. F. and Jacoby, L. L. (1999). Separating habit and recollection in young and older adults: Effects of elaborative processing and distinctiveness. *Psychology and Aging*, *14*, 122–134.

Hebb, D. O. (1949). *The Organization of Behavior: A Neuropsychological Theory*. New York, NY: Wiley.

Hebb, D. O. (1968). Concerning imagery. *Psychological Review*, *75*, 466–477. https://doi.org/10.1037/h0026771

Henry, J. D., MacLeod, M. S., Phillips, L. H., and Crawford, J. R. (2004). A meta-analytic review of prospective memory and aging. *Psychology and Aging*, *19*, 27–39. doi.org/10.1037/0882-7974.19.1.27.

Heron, A. and Craik, F. I. M. (1964). Age differences in cumulative learning of meaningful and meaningless material. *Scandinavian Journal of Psychology*, *5*, 209–217. doi.org/10.1111/j.1467-9450.1964.tb01426.x

Hintzman, D. L. (2011). Research strategy in the study of memory: Fads, fallacies, and the search for the "coordinates of truth". *Perspectives on Psychological Science*, *6*, 253–271. https://doi.org/10.1177/1745691611406924

Hitch, G. J., Allen, R. J., and Baddeley, A. D. (2020). Attention and binding in visual working memory: two forms of attention and two kinds of buffer storage. *Attention*, *Perception*, *&* *Psychophysics*, *82*, 280–293.

Hülür, G., Ram, N., Willis, S. L., et al. (2015). Cognitive dedifferentiation with increasing age and proximity of death: Within-person evidence from the Seattle Longitudinal Study. *Psychology and Aging*, *30*, 311–323.

Hunt, R. R. and McDaniel, M. A. (1993). The enigma of organization and distinctiveness. *Journal of Memory and Language*, *32*, 421–445. https://doi.org/10.1006/jmla.1993.1023

Hunt, R. R. and Worthen, J. B. (Eds.) (2006). Distinctiveness and memory. New York: Oxford University Press.

Hutchins, E. (1995). *Cognition in the Wild*. London: The MIT Press.

Hutchins, E. (2014). The cultural ecosystem of human cognition. *Philosophical Psychology*, *27*, 34–49.

Hyde, T. S. (1973). Differential effects of effort and type of orienting task on recall and organization of highly associated words. *Journal of Experimental Psychology*, *97*, 111–113. doi: 10.1037/h0033780.

Hyde, T. S. and Jenkins, J. J. (1969). Differential effects of incidental tasks on the organization of recall of a list of highly associated words. *Journal of Experimental Psychology*, *82*, 472–481. doi: 10.1037/h0028372.

Hyde, T. S. and Jenkins, J. J. (1973). Recall for words as a function of semantic, graphic, and syntactic orienting tasks. *Journal of Verbal Learning and Verbal Behavior*, *12*, 471–480. doi: 10.1016/S0022-5371(73)80027-1.

Ittelson, W. H. (1962). Perception and transactional psychology. In: F. Ratliff and S. Koch (Eds.), *Psychology: A Study of a Science* (pp. 660–704). New York, NY: McGraw Hill.

Jackson, A. and Morton, J. (1984). Facilitation of auditory word recognition. *Memory & Cognition*, *12*, 568–574.

Jacoby, L. L. (1978). On interpreting the effects of repetition: Solving a problem versus remembering a solution. *Journal of Verbal Learning and Verbal Behavior*, *17*, 649–667.

Jacoby, L. L. (1983). Remembering the data: Analyzing interactive processes in reading. *Journal of Verbal Learning and Verbal Behavior*, *22*, 485–508.

Jacoby, L. L. (1991). A process dissociation framework: Separating automatic from intentional uses of memory. *Journal of Memory and Language*, *30*, 513–541.

Jacoby, L. L. and Bartz, W. H. (1972). Rehearsal and transfer to LTM. *Journal of Verbal Learning & Verbal Behavior*, *11*, 561–565. https://doi.org/10.1016/S0022-5371(72)80039-2

Jacoby, L. L. and Craik, F. I. M. (1979). Effects of elaboration of processing at encoding and retrieval: Trace distinctiveness and recovery of initial context. In: L. S. Cermak and F. I. M. Craik (Eds.), *Levels of Processing and Human Memory* (pp. 1-21) Hillsdale, NJ: LEA.

Jacoby, L. L. and Dallas, M. (1981). On the relationship between autobiographical memory and perceptual learning. *Journal of Experimental Psychology: General*, *110*, 306–340. doi: 10.1037//0096-3445.110.3.306.

Jacoby, L. L. and Whitehouse, K. (1989). An illusion of memory: False recognition influenced by unconscious perception. *Journal of Experimental Psychology: General*, *118*, 126–135.

Jacoby, L. L. and Witherspoon, D. (1982). Remembering without awareness. *Canadian Journal of Psychology*, *36*, 300–324.

Jacoby, L. L., Allan, L. G., Collins, J. C., and Larwill, L. K. (1988). Memory influences subjective experience: Noise judgements. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *14*, 240–247.

Jacoby, L. L., Kelley, C. M., and Dywan, J. (1989). Memory attributions. In: H. L. Roediger III and F. I. M. Craik (Eds.), *Varieties of Memory and Consciousness: Essays in Honour of Endel Tulving* (pp. 391–422). New York, NY: Lawrence Erlbaum Associates, Inc.

Jacoby, L. L., Shimizu, Y., Daniels, K. A., and Rhodes, M. G. (2005a). Modes of cognitive control in recognition and source memory: Depth of retrieval. *Psychonomic Bulletin and Review*, *12*, 852–857.

Jacoby, L. L., Shimizu, Y., Velanova, K., and Rhodes, M. G. (2005b). Age differences in depth of retrieval: Memory for foils. *Journal of Memory and Language*, *52*, 493–504.

Jacoby, L. L., Wahlheim, C. N., and Kelley, C. M. (2015). Memory consequences of looking back to notice change: Retroactive and proactive facilitation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *41*, 1282–1297. https://doi.org/10.1037/xlm0000123

James, W. (1890). *The Principles of Psychology*. London: Macmillan.

Jenkins, J. G. and Dallenbach, K. M. (1924). Oblivescence during sleep and waking. *The American Journal of Psychology*, *35*, 605–612. doi: 10.2307/1414040.

Jenkins, J. J. (1974). Remember that old theory of memory? Well, forget it. *American Psychologist*, *29*, 785–795. https://doi.org/10.1037/h0037399

Jenkins, J. J. (1979). Four points to remember: A tetrahedral model of memory experiments. In: L. S. Cermak and F. I. M. Craik (Eds.), *Levels of Processing in Human Memory* (pp. 229–446). Hillsdale, NJ: Lawrence Erlbaum Associates.

Jenkins, J. J. and Russell, W. A. (1952). Associative clustering during recall. *The Journal of Abnormal and Social Psychology*, *47*, 818–821. doi: 10.1037/h0063149.

Jennings, J. M. and Jacoby, L. L. (1993). Automatic versus intentional uses of memory: Aging, attention, and control. *Psychology and Aging*, *8*, 283–293.

Jennings, J. M. and Jacoby, L. L. (1997a). An opposition procedure for detecting age-related deficits in recollection: Telling effects of repetition. *Psychology and Aging*, *12*, 352–361. https://doi.org/10.1037/0882-7974.12.2.352

Johnson, J. D. and Rugg, M. D. (2007). Recollection and the reinstatement of encoding-related cortical activity. *Cerebral Cortex*, *17*, 2507–2515. doi: 10.1093/cercor/bhl156.

Johnston, C. D. and Jenkins, J. J. (1971). Two more incidental tasks that differentially affect associative clustering in recall. *Journal of Experimental Psychology*, *89*, 92–95. doi: 10.1037/h0031184.

Jones, B. M. and Jones, M. K. (1977). Alcohol and memory impairments in male and female social drinkers. In: I. M. Birnbaum and E. S. Parker (Eds.), *Alcohol and Human Memory* (pp. 127–138), Hillsdale, NJ: Lawrence Erlbaum.

Josselyn, S. A., Köhler, S., and Frankland, P. W. (2015). Finding the engram. *Nature Reviews Neuroscience*, *16*, 521–534.

Kahana, M. J. (2012). *Foundations of Human Memory*. New York, NY: Oxford University Press.

Kahneman, D. (1973). *Attention and Effort*. Englewood Cliffs, NJ: Prentice-Hall.

Kane, M. J. and Engle, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. *Psychonomic Bulletin & Review*, *9*, 637–671.

Kane, M. J. and Engle, R. W. (2003). Working-memory capacity and the control of attention: The contributions of goal neglect, response competition, and task set to Stroop interference. *Journal of Experimental Psychology: General*, *132*, 47–70. https://doi.org/10.1037/0096-3445.132.1.47

Kane, M. J., Brown, L. H., McVay, J. C., et al. (2007). For whom the mind wanders, and when: An experience-sampling study of working memory and executive control in daily life. *Psychological Science*, *18*, 614–621. doi: 10.1111/j.1467-9280.2007.01948.x.

Kane, M. J., Hambrick, D. Z., Tuholski, S. W., et al. (2004). The generality of working memory capacity: A latent-variable approach to verbal and visuospatial memory span and reasoning. *Journal of Experimental Psychology: General*, *133*, 189–217.

Kapur, S., Craik, F. I. M., Tulving, E., et al. (1994). Neuroanatomical correlates of encoding in episodic memory: Levels of processing effect. *Proceedings of the National Academy of Sciences*, *91*, 2008–2011.

Karpicke, J. D. and Roediger, H. L., III. (2008). The critical importance of retrieval for learning. *Science*, *319*, 966–968. doi: 10.1126/science.1152408.

Kerr, S. A. (1991). *Prospective Memory and Aging*. Unpublished M. A. Thesis, University of Toronto.

Kilpatrick, F. P. (Ed.). (1961). *Explorations in Transactional Psychology*. New York, NY: New York University Press. doi: 10.1037/11303-000.

Kirsner, K. (1973). An analysis of the visual component in recognition memory for verbal stimuli. *Memory & Cognition*, *1*, 449–453.

Kirsner, K. (1974). Modality differences in recognition memory for words and their attributes. *Journal of Experimental Psychology*, *102*, 579–584. doi: 10.1037/h0036112.

Klein, S. B. and Kihlstrom, J. F. (1986). Elaboration, organization, and the self-reference effect in memory. *Journal of Experimental Psychology: General*, *115*, 26–38. doi: 10.1037/0096-3445.115.1.26.

Klein, S. B. and Loftus, J. (1988). The nature of self-referent encoding. The contributions of elaborative and organizational processes. *Journal of Personality and Social Psychology*, *55*, 5–11. doi: 10.1037/0022-3514.55.1.5.

Kliegel M., McDaniel M. A., and Einstein G. O. (2000). Plan formation, retention, and execution in prospective memory: A new approach and age-related differences. *Memory & Cognition*, *28*, 1041–1049.

Koen, J. D. and Yonelinas, A. P. (2014). The effects of healthy aging, amnestic mild cognitive impairment, and Alzheimer's disease on recollection and familiarity: A meta-analytic review. *Neuropsychology Review*, *24*, 332–354. https://doi.org/10.1007/s11065-014-9266-5

Koen, J. D. and Yonelinas, A. P. (2016). Recollection, not familiarity, decreases in healthy ageing: Converging evidence from four estimation methods. *Memory*, *24*, 75–88

Kolers, P. A. (1973). Remembering operations. *Memory & Cognition*, *1*, 347–355. doi: 10.3758/bf03198119.

Kolers, P. A. (1975). Memorial consequences of automatized encoding. *Journal of Experimental Psychology: Human Learning and Memory*, *1*, 689–701. doi: 10.1037/0278-7393.1.6.689.

Kolers, P. A. (1976). Reading a year later. *Journal of Experimental Psychology: Human Learning and Memory*, *2*, 554–565. doi: 10.1037/0278-7393.2.5.554.

Kolers, P. A. (1979). A pattern-analyzing basis of recognition. In: L. S. Cermak and F. I. M. Craik (Eds.), *Levels of Processing in Human Memory* (pp. 363–384). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Kolers, P. A. and Roediger, H. L., III. (1984). Procedures of mind. *Journal of Verbal Learning and Verbal Behavior*, *23*, 425–449.

Koriat, A., Ben-Zur, H., and Nussbaum, A. (1990). Encoding information for future action: Memory for to-be-performed tasks versus memory for to-be-recalled tasks. *Memory & Cognition*, *18*, 568–578.

Koriat, A., Goldsmith, M., and Pansky, A. (2000). Toward a psychology of memory accuracy. *Annual Review of Psychology*, *51*, 481–537.

Kovacs, K. and Conway, A. R. A. (2016). Process overlap theory: A unified account of the general factor of intelligence. *Psychological Inquiry*, *27*, 151–177. doi.org/10.1080/1047840X.2016.1153946.

Kuhn, J. R., Lohnas, L. J., and Kahana, M. J. (2018). A spacing account of negative recency in final free recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *44*, 1180–1185. https://doi.org/10.1037/xlm0000491

Kvavilashvili, L. and Mandler, G. (2004). Out of one's mind: A study of involuntary semantic memories. *Cognitive Psychology*, *48*, 47–94

Kyllonen, P. C. (1996). Is working memory capacity Spearman's g? In: I. Dennis and P. Tapsfield (Eds.), *Human Abilities: Their Nature and Measurement* (pp. 49–75). New York, NY: Lawrence Erlbaum Associates, Inc.

La Voie, D. and Light, L. L. (1994). Adult age differences in repetition priming: A meta-analysis. *Psychology and Aging*, *9*, 539–553. doi: 10.1037/0882-7974.9.4.539.

Lee, A. C. H., Yeung, L-K., and Barense, M. D. (2012). The hippocampus and visual perception. *Frontiers in Human Neuroscience*, *6*, 91.

Lepage, M., Ghaffar, O., Nyberg, L., and Tulving, E. (2000). Prefrontal cortex and episodic memory retrieval mode. *Proceedings of the National Academy of Sciences of the United States of America*, *97*, 506–511.

Levine, B., Svoboda E., Hay, J. F., et al. (2002). Aging and autobiographical memory: dissociating episodic from semantic retrieval. *Psychology and Aging*, *17*, 677–689.

Levy, B. A. and Baddeley, A. (1971). Recall of semantic clusters in primary memory. *The Quarterly Journal of Experimental Psychology*, *23*, 8–13. https://doi.org/10.1080/00335557143000013

Levy, B. A. and Craik, F. I. M. (1975). The co-ordination of codes in short-term retention. *Quarterly Journal of Experimental Psychology*, *27*, 33–45. doi: 10.1080/14640747508400462.

Lhermitte, F., Pillon, B., and Serdaru, M. (1986). Human autonomy and the frontal lobes. Part I: Imitation and utilization behavior: A neuropsychological study of 75 patients. *Annals of Neurology*, *19*, 326–334.

Lindenberger, U. and Baltes, P. B. (1994). Sensory functioning and intelligence in old age: A strong connection. *Psychology and Aging*, *9*, 339–355.

Lindenberger, U. and Mayr, U. (2014). Cognitive aging: Is there a dark side to environmental support? *Trends in Cognitive Sciences*, *18*, 7–15. doi: 10.1016/j.tics.2013.10.006.

Lindenberger, U. and von Oertzen, T. (2006). Variability in cognitive aging: From taxonomy to theory. In: E. Bialystok and F. I. M. Craik (Eds.), *Lifespan Cognition: Mechanisms of Change* (pp. 297–314). New York, NY: Oxford University Press. https://doi.org/10.1093/acprof:oso/9780195169539.003.0021

Lockhart, R. S. (2001). Commentary: Levels of processing and memory theory. In: M. Naveh-Benjamin, M. Moscovitch, and H. L. Roediger, III (Eds.), *Perspectives on Human Memory and Cognitive Aging: Essays in Honour of Fergus Craik* (pp. 99–102). New York: Psychology Press.

Lockhart, R.S. (2002). Levels of processing, transfer-appropriate processing, and the concept of robust encoding. *Memory*, *10*, 397-403.

Lockhart, R. S. and Craik, F. I. M. (1978). Levels of processing: A reply to Eysenck. *British Journal of Psychology*, *69*, 171–175. doi: 10.1111/j.2044-8295.1978.tb01644.x.

Lockhart, R. S. and Craik, F. I. M. (1990). Levels of processing: A retrospective commentary on a framework for memory research. *Canadian Journal of Psychology/Revue canadienne de psychologie*, *44*, 87–112. doi: 10.1037/h0084237.

Lockhart, R. S., Craik, F. I. M., and Jacoby, L. (1976). Depth of processing, recognition and recall. In: J. Brown (Ed.), *Recall and Recognition* (pp. 75-102). Oxford: John Wiley & Sons.

Loftus, E. F. (1983). Misfortunes of memory. *Philosophical Transactions of the Royal Society of London*, *302*, 413–421.

Logie, R. H. (1995). *Visuospatial working memory*. Hillsdale, NJ: Erlbaum.

Logie, R. H. (2003). Spatial and visual working memory: A mental workspace. *The Psychology of Learning and Motivation*, *42*, 37–78.

Logie, R. H. (2011). The functional organization and capacity limits of working memory. *Current Directions in Psychological Science*, *20*, 240–245.

Lozito, J. P. and Mulligan, N. W. (2006). Exploring the role of attention during memory retrieval: Effects of semantic encoding and divided attention. *Memory & Cognition*, *34*, 986–998. https://doi.org/10.3758/BF03193246

Luck, S. J. and Vogel, E. K. (2013). Visual working memory capacity: from psychophysics and neurobiology to individual differences. *Trends in Cognitive Sciences*, *17*, 391–400.

Luo, L., Hendriks, T., and Craik, F. I. M. (2007). Age differences in recollection: Three patterns of enhanced encoding. *Psychology and Aging*, *22*, 269–280.

Luria, A. R. (1966). *Higher Cortical Functions in Man*. New York, NY: Basic Books.

Luria, A. R. (1973). *The Working Brain*. New York, NY: Basic Books.

Mace, J. H. and Unlu, M. (2020). Semantic-to-autobiographical memory priming occurs across multiple sources: Implications for autobiographical remembering. *Memory & Cognition*, *48*, 931–941

McBride, D. M. and Workman, R. A. (2017). Is prospective memory unique? A comparison of prospective and retrospective memory. *Psychology of Learning and Motivation*, *67*, 213–238. doi: 10.1016/bs.plm.2017.03.007.

McClelland, J. L., McNaughton, B. L., and O'Reilly, R. C. (1995). Why there are complementary learning systems in the hippocampus and neocortex: Insights from the successes and failures of connectionist models of learning and memory. *Psychological Review*, *102*, 419–457. https://doi.org/10.1037/0033-295X.102.3.419

McDaniel, M. A. and Einstein, G. O. (2000). Strategic and automatic processes in prospective memory retrieval: A multiprocess framework. *Applied Cognitive Psychology*, *14*, S127–S144.

McDaniel, M. A. and Einstein, G. O. (2011). The neuropsychology of prospective memory on normal aging: A componential approach. *Neuropsychologia*, *49*, 2147–2155.

McIntosh, A. R. (1999) Mapping cognition to the brain through neural interactions. *Memory*, *7*, 523–548.

McIntyre, J. S. and Craik, F. I. M. (1987). Age differences in memory for item and source information. *Canadian Journal of Psychology*, *41*, 175–192.

MacLeod, C. M. (2011). I said, you said: the production effect gets personal. *Psychonomic Bulletin & Review*, *18*, 1197–1202. doi: 10.3758/s13423-011-0168-8.

MacLeod, C. M., Gopie, N., Hourihan, K. L., et al. (2010). The production effect: Delineation of a phenomenon. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *36*, 671–685. doi: 10.1037/a0018785.

Maillet, D. and Schacter, D. L. (2016a). From mind wandering to involuntary retrieval: Age-related differences in spontaneous cognitive processes. *Neuropsychologia*, *80*, 142–156. doi: 10.1016/j.neuropsychologia.2015.11.017.

Maillet, D. and Schacter, D. L. (2016b). When the mind wanders: Distinguishing stimulus-dependent from stimulus-independent thoughts during incidental encoding in young and older adults. *Psychology and Aging*, *31*, 370–379. Doi: 10.1037/pag0000099.

Mandler, G. (1962). From association to structure. *Psychological Review*, *69*, 415–427. doi: 10.1037/h0048889.

Mandler, G. (1967). Organization and memory. In: Spence, K.W. and Spence, J.T. (Eds.), *The Psychology of Learning and Motivation: Advances in Research and Theory* (pp. 328–372). New York, NY: Academic Press.

Mandler, G. (1979). Organization and repetition: Organizational principles with special reference to rote learning. In: L. Nilsson (Ed.), *Perspectives on Memory Research* (pp. 293–327). Hillsdale, NJ: Erlbaum.

Mandler, G. (1980). Recognizing: The judgment of previous occurrence. *Psychological Review*, *87*, 252–271. doi: 10.1037//0033-295x.87.3.252.

Mäntylä, T. (1986). Optimizing cue effectiveness: Recall of 500 and 600 incidentally learned words. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *12*, 66–71.

Mason, M. F., Norton, M. I., Van Horn, J. D., et al. (2007). Wandering minds: The default network and stimulus-independent thought. *Science*, *315*, 393–395. https://doi.org/10.1126/science.1131295

May, C. P., Hasher, L., and Stoltzfus, E. R. (1993). Optimal time of day and the magnitude of age differences in memory. *Psychological Science*, *4*, 326–330. https://doi.org/10.1111/j.1467-9280.1993.tb00573.x

Meier, M. E. (2019). Is there a positive association between working memory capacity and mind wandering in a low-demand breathing task? A preregistered replication of a study by Levinson, Smallwood, and Davidson (2012). *Psychological Science*, *30*, 789–797. https://doi.org/10.1177/0956797619837942

Melton, A. W. (1963). Implications of short-term memory for a general theory of memory. *Journal of Verbal Learning and Verbal Behavior*, *2*, 1–21.

Melton, A. W. (1970). The situation with respect to the spacing of repetitions and memory. *Journal of Verbal Learning and Verbal Behavior*, *9*, 596–606.

Meshcheriakov, B. G. (2008). The mnemic effects of P. I. Zinchenko. *Journal of Russian and East European Psychology*, *46*, 15–40. doi: 10.2753/rpo1061-0405460602.

Michaelian, K. andSutton, J. (2013). Distributed cognition and memory research: History and current directions. *Review of Philosophy and Psychology*, *4*, 1–24.

Middleton, D. (1987). Collective memory and remembering: Some issues and approaches. *Quarterly Newsletter of the Laboratory of Comparative Human Cognition*, *9*, 2–5.

Miller, G. A. (1956). The magical number seven, plus or minus two: some limits on our capacity for processing information. *Psychological Review*, *63*, 81–97. https://doi.org/10.1037/h0043158

Monsell, S. (1984). Components of working memory underlying verbal skills: A "distributed capacities" view. In: H. Bourna and D. Bouwhuis (Eds.), *Attention and Performance X* (pp. 327–350). Hillsdale, NJ: Erlbaum.

Moray, N. (1959). Attention in dichotic listening: Affective cues and the influence of instructions. *The Quarterly Journal of Experimental Psychology*, *11*, 56–60. https://doi.org/10.1080/17470215908416289

Morcom, A. M. (2014). Re-engaging with the past: recapitulation of encoding operations during episodic retrieval. *Frontiers in Human Neuroscience*, *8*, 351.

Morcom, A. M. and Henson, R. N. A. (2018). Increased prefrontal activity with aging reflects nonspecific neural responses rather than compensation. *Journal of Neuroscience*, *38*, 7303–7313

Morris, C. D., Bransford, J. D., and Franks, J. J. (1977). Levels of processing versus transfer appropriate processing. *Journal of Verbal Learning and Verbal Behavior*, *16*, 519–533. doi: 10.1016/s0022-5371(77)80016-9.

Morrow, D. G. and Rogers, W. A. (2008). Environmental support: An integrative framework. *Human Factors*, *50*, 589–613. https://doi.org/10.1518/001872008X312251

Moscovitch, M. (1992). Memory and working-with-memory: A component process model based on modules and central systems. *Journal of Cognitive Neuroscience*, *4*, 257–267.

Moscovitch, M. (1994). Memory and working with memory: Evaluation of a component process model and comparisons with other models. In: D. L. Schacter and E. Tulving (Eds.), *Memory Systems 1994* (pp. 269–310). Cambridge, MA: The MIT Press.

Moscovitch, M. (2007). Memory: Why the engram is elusive. In: H. L. Roediger III, Y. Dudai, and S. M. Fitzpatrick (Eds.), *Science of Memory: Concepts* (pp. 17–21) Oxford: Oxford University Press.

Moscovitch, M. and Craik, F. I. M. (1976). Depth of processing, retrieval cues, and uniqueness of encoding as factors in recall. *Journal of Verbal Learning and Verbal Behavior*, *15*, 447–458.

Moscovitch, M. and Winocur, G. (1992). The neuropsychology of memory and aging. In: F. I. M. Craik and T. A. Salthouse (Eds.), *The Handbook of Aging and Cognition* (pp. 315–372). Hillsdale, NJ: Erlbaum.

Moscovitch, M., Cabeza, R., Winocur, G., and Nadel, L. (2016). Episodic memory and beyond: The hippocampus and neocortex in transformation. *Annual Review of Psychology*, *67*, 105–134

Moulin, C. J. A., Conway, M. A., Thompson, R. G., et al. (2005). Disordered memory awareness: Recollective confabulation in two cases of persistent déjà vécu. *Neuropsychologia*, *43*, 1362–1378. https://doi.org/10.1016/j.neuropsychologia.2004.12.008

Multhaup, K. S. (1995). Aging, source, and decision criteria: When false fame errors do and do not occur. *Psychology and Aging*, *10*, 492–497. https://doi.org/10.1037/0882-7974.10.3.492

Murdock, B. B., Jr (1961). The retention of individual items. *Journal of Experimental Psychology*, *62*, 618–625. https://doi.org/10.1037/h0043657

Murdock, B. B., Jr. (1965). Effects of a subsidiary task on short-term memory. *British Journal of Psychology*, *56*, 413–419. https://doi.org/10.1111/j.2044-8295.1965.tb00983.x

Murdock, B. B., Jr (1967). Recent developments in short-term memory. *British Journal of Psychology*, *58*, 421–433. https://doi.org/10.1111/j.2044-8295.1967.tb01099.x

Murdock, B. B., Jr (1974). *Human Memory: Theory and Data*. Potomac, MD: Lawrence Erlbaum.

Murray, E. A., Wise, S. P., and Graham, K. S. (2017). *The Evolution of Memory Systems: Ancestors, Anatomy, and Adaptations*. Oxford: Oxford University Press.

Muter, P. (1980). Very rapid forgetting. *Memory & Cognition*, *8*, 174–179. https://doi.org/10.3758/BF03213420

Nadel, L., and Peterson, M. A. (2013). The hippocampus: Part of an interactive posterior representational system spanning perceptual and memorial systems. *Journal of Experimental Psychology General*, *142*, 1242–1254.

Naveh-Benjamin, M. (2000). Adult age differences in memory performance: Tests of an associative deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *26*, 1170–1187.

Naveh-Benjamin, M. (2001). The effects of divided attention on encoding processes: Underlying mechanisms. In: M. Naveh-Benjamin, M. Moscovitch M, and H. L. Roediger, III, (Eds.), *Perspectives on Human Memory and Cognitive Aging: Essays in Honour of Fergus Craik* (pp. 193–207). Philadelphia, PA: Psychology Press.

Naveh-Benjamin, M. and Craik, F. I. M. (1995). Memory for context and its utilization in item memory: Comparisons of young and old. *Psychology and Aging*, *10*, 284–293.

Naveh-Benjamin, M. and Craik, F. I. M. (1996). Effects of perceptual and conceptual processing on memory for words and voice: Different patterns for young and old. *Quarterly Journal of Experimental Psychology*, *49A*, 780–796.

Naveh-Benjamin, M., Craik, F. I. M., Guez, J., and Kreuger, S. (2005). Divided attention in younger and older adults: Effects of strategy and relatedness on memory performance and secondary task costs. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *31*, 520–537.

Neisser, U. (1967). *Cognitive Psychology*. New York: Appleton-Century-Crofts.

Nelson, D. L. (1979). Remembering pictures and words: Appearance, significance and name. In: L. S. Cermak and F. I. M. Craik (Eds.), *Levels of Processing in Human Memory* (pp. 45–76). Hillsdale, NJ: Erlbaum.

Nelson, D. L., Reed, V. S., and Walling, J. R. (1976). Pictorial superiority effect. *Journal of Experimental Psychology: Human Learning and Memory*, *2*, 523–528.

Nelson, K. (1984). The transition from infant to child memory. In: M. Moscovitch (Ed.), *Infant Memory* (pp. 75-87). New York: Plenum.

Nelson, T. O. (1977). Repetition and depth of processing. *Journal of Verbal Learning and Verbal Behavior*, *16*, 151–171. doi: 10.1016/s0022-5371(77)80044-3.

Nilsson, L. G., Nyberg, L., Klingberg, T., et al. (2000). Activity in motor areas while remembering action events. *NeuroReport*, *11*, 2199–2201.

Norman, D. A. and Bobrow, D. G. (1979). Descriptions: An intermediate stage in memory retrieval. *Cognitive Psychology*, *11*, 107–123.

Norman D.A. and Shallice T. (1986) Attention to action. In: R. J. Davidson, G. E. Schwartz, and D. Shapiro (Eds.), *Consciousness and Self-Regulation: Advances in Research, Vol. 4* (pp. 1–18). New York, NY: Plenum Press.

Nyberg, L., Habib, R., McIntosh, A. R., and Tulving, E. (2000). Reactivation of encoding-related brain activity during memory retrieval. *Proceedings of the National Academy of Sciences in the USA*, *97*, 11120–11124.

Nyberg, L., Lövdén, M., Riklund, K., et al. (2012). Memory aging and brain maintenance. *Trends in Cognitive Science*, *16*, 292–305.

Oberauer, K. (2009). Design for a working memory. *Psychology of Learning and Motivation*, *51*, 45–100. doi: 10.1016/S0079-7421(09)51002-X.

Oberauer, K. and Hein, L. (2012). Attention to information in working memory. *Current Directions in Psychological Science*, *21*, 164–169. https://doi.org/10.1177/0963721412444727

Oberauer, K., Lewandowsky, S., Awh, E., et al. (2018). Benchmarks for models of short-term and working memory. *Psychological Bulletin*, *144*, 885–958. https://doi.org/10.1037/bul0000153

Oberauer, K., Süß, H., Schulze, R., et al. (2000). Working memory capacity—facets of a cognitive ability construct. *Personality and Individual Differences*, *29*, 1017–1045. doi: 10.1016/s0191-8869(99)00251-2.

Otten, L. J., Henson, R. N. A., and Rugg, M. D. (2001). Depth of processing effects on neural correlates of memory encoding: Relationship between findings from across- and within-task comparisons. *Brain*, *124*, 399–412.

Paivio, A. (1971). *Imagery and Verbal Processes*. New York, NY: Holt, Rinehart & Winston.

Palmeri, T. J., Goldinger, S. D., and Pisoni, D. B. (1993). Episodic encoding of voice attributes and recognition memory for spoken words. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *19*, 309–328. https://doi.org/10.1037/0278-7393.19.2.309

Park, D. C., Polk, T. A., Park, R., et al. (2004). Aging reduces neural specialization in ventral visual cortex. *Proceedings of the National Academy of Sciences of the USA*, *101*, 13091–13095.

Passow, S., Westerhausen, R., Wartenburger, I., et al. (2012). Human aging compromises attentional control of auditory perception. *Psychology and Aging*, *27*, 99–105. doi: 10.1037/a0025667.

Penfield, W. (1975). *The Mystery of the Mind: A Critical Study of Consciousness and the Human Brain*. Princeton, NJ: Princeton University Press.

Penfield, W. and Perot, P. (1963). The brain's record of auditory and visual experience. A final summary and discussion. *Brain*, *86*, 595–696.

Petersen, S. E. and Fiez, J. A. (1993). The processing of single words studied with positron emission tomography. *Annual Review of Neuroscience*, *16*, 509–530. doi: 10.1146/annurev.ne.16.030193.002453.

Peterson, L. and Peterson, M. J. (1959). Short-term retention of individual verbal items. *Journal of Experimental Psychology*, *58*, 193–198. https://doi.org/10.1037/h0049234

Petersen, S. E. and Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience*, *35*, 73–89. https://doi.org/10.1146/annurev-neuro-062111-150525

Petersen, S. E., Fox, P. T., Posner, M. I., et al. (1988). Positron emission tomographic studies of the cortical anatomy of single-word processing. *Nature*, *331*, 585–589.

Petersen, S. E., Fox, P. T., Posner, M. I., et al. (1989). Positron emission tomographic studies of the processing of single words. *Journal of Cognitive Neuroscience*, *1*, 153–170. doi: 10.1162/jocn.1989.1.2.153.

Phillips, S. and Williams, J. M. G. (2011). Cognitive impairment, depression and the specificity of autobiographical memory in the elderly. *British Journal of Clinical Psychology*, *36*, 341–347.

Pisoni, D. B. (1993). Long-term memory in speech perception: Some new findings on talker variability, speaking rate and perceptual learning. *Speech Communication*, *13*, 109–125. https://doi.org/10.1016/0167-6393(93)90063-Q

Poppenk, J., McIntosh, A.R., Craik, F.I.M., and Moscovitch, M. (2010). Prior experience modulates the neural mechanisms of episodic memory formation. *Journal of Neuroscience*, *30*, 4707–4716.

Posner, M. I. and Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience*, *13*, 25–42. https://doi.org/10.1146/annurev.ne.13.030190.000325

Postle, B. R. (2006). Working memory as an emergent property of the mind and brain. *Neuroscience*, *139*, 23–38.

Postman, L. (1964). Studies of learning to learn II. Changes in transfer as a function of practice. *Journal of Verbal Learning and Verbal Behavior*, *3*, 437–447. doi: 10.1016/s0022-5371(64)80014-1

Rabinowitz, J. C. and Craik, F. I. M. (1986). Specific enhancement effects associated with word generation. *Journal of Memory and Language*, *25*, 220–231.

Rabinowitz, J. C., Craik, F. I. M., and Ackerman, B. P. (1982). A processing resource account of age differences in recall. *Canadian Journal of Psychology*, *36*, 325–344.

Raichle, M. E. (2010). Two views of brain function. *Trends in Cognitive Science*, *14*, 180–190.

Raichle, M. E. (2015). The restless brain: How intrinsic activity organizes brain function. *Philosophical Transactions of the Royal Society B*, *Biological Sciences*, *370*, 1–11.

Raichle, M. E., Fiez, J. A., Videen, T. O., et al. (1994). Practice-related changes in human brain functional anatomy during nonmotor learning. *Cerebral Cortex*, *4*, 8–26.

Raichle, M. E., MacLeod, A. M., Snyder, A. Z., et al. (2001). A default mode of brain function. *Proceedings of the National Academy of Sciences*, *98*, 676–682.

Rajaram, S. and Geraci, L. (2000). Conceptual fluency selectively influences knowing. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *26*, 1070–1074. doi: 10.1037/0278-7393.26.4.1070.

Ramanan, S. (2017). Distinct neural networks support autobiographical and episodic remembering. *Journal of Neuroscience*, *37*, 5591–5593.

Rasch, B. and Born. J. (2013). About sleep's role in memory. *Physiological Review*, *93*, 681–766. doi: 10.1152/physrev.00032.2012.

Ratcliff, R., Smith, P. L., Brown, S. D., and McKoon, G. (2016). Diffusion decision model: Current issues and history. *Trends in Cognitive Sciences*, *20*, 260–281. https://doi.org/10.1016/j.tics.2016.01.007

Raymond, B. (1969). Short-term storage and long-term storage in free recall. *Journal of Verbal Learning & Verbal Behavior*, *8*, 567–574. https://doi.org/10.1016/S0022-5371(69)80106-4

Raz, N. (2000). Aging of the brain and its impact on cognitive performance: Integration of structural and functional findings. In: F. I. M. Craik and T. A. Salthouse (Eds.), *The Handbook of Aging and Cognition* (pp. 1–90). Mahwah, NJ: Lawrence Erlbaum Associates Publishers.

Redick, T. S., Broadway, J. M., Meier, M. E., et al. (2012a). Measuring working memory capacity with automated complex span tasks. *European Journal of Psychological Assessment*, *28*, 164–171.

Redick, T. S., Unsworth, N., Kelly, A. J., and Engle, R. W. (2012b). Faster, smarter? Working memory capacity and perceptual speed in relation to fluid intelligence. *Journal of Cognitive Psychology*, *24*, 844–854

Resnick, L. B., Levine, J. M., and Behrend, S. D. (1991). *Socially Shared Cognition*. Arlington, VA: American Psychological Association.

Rips, L. J., Shoben E. J., and Smith E. E. (1973). Semantic distance and the verification of semantic relations. *Journal of Verbal Learning and Verbal Behavior*, *12*, 1–20.

Rissman, J. and Wagner, A. D. (2012). Distributed representations in memory: Insights from functional brain imaging. *Annual Review of Psychology*, *63*, 101–128. https://doi.org/10.1146/annurev-psych-120710-100344

Roediger, H. L., III. (1990). Implicit memory: Retention without remembering. *American Psychologist*, *45*, 1043–1056. https://doi.org/10.1037/0003-066X.45.9.1043

Roediger, H. L., III. (2000). Why retrieval is the key process in understanding human memory. In: E. Tulving (Ed.), *Memory, Consciousness, and the Brain: The Tallinn Conference* (pp. 52–75). New York, NY: Taylor & Francis.

Roediger, H. L., III, and Blaxton, T. A. (1987a). Effects of varying modality, surface features, and retention interval on priming in word fragment completion. *Memory and Cognition*, *15*, 379–388.

Roediger, H. L., III, and Blaxton, T. A. (1987b). Retrieval modes produce dissociations in memory for surface information. In: D. Gorfein and R. R. Hoffman (Eds.), *Memory and Cognitive Processes: The Ebbinghaus Centennial Conference* (pp. 349–379). Hillsdale, NJ: Erlbaum.

Roediger, H. L., III, and Gallo, D. A. (2001). Levels of processing: Some unanswered questions. In: M. Naveh-Benjamin, M. Moscovitch, and H. L. Roediger (Eds.), *Perspectives on Human Memory and Cognitive Aging: Essays in Honour of Fergus Craik* (pp. 28–47). New York: Psychology Press.

Roediger, H. L., III, and Karpicke, J. D. (2006). Test-enhanced learning: Taking memory tests improves long-term retention. *Psychological Science*, *17*, 249–255.

Roediger, H. L., III, and McDermott, K. B. (1995). Creating false memories: Remembering words not presented in lists. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*, 803–814. doi: 10.1037/0278-7393.21.4.803.

Roediger, H. L., III, Weldon, M. S., and Challis, B. H. (1989). Explaining dissociations between implicit and explicit measures of retention: A processing account. In: H. L. Roediger III and F. I. M. Craik (Eds.), *Varieties of Memory and Consciousness: Essays in Honour of Endel Tulving* (pp. 3–42). Hillsdale, NJ: Lawrence Erlbaum Associates.

Rogers, T. B., Kuiper, N. A., and Kirker, W. S. (1977). Self-reference and the encoding of personal information. *Journal of Personality and Social Psychology*, *35*, 677–688.

Rohrer, D. and Pashler, H. E. (2003). Concurrent task effects on memory retrieval. *Psychonomic Bulletin & Review*, *10*, 96–103. https://doi.org/10.3758/BF03196472

Rolls, E. T. (2013). The mechanisms for pattern completion and pattern separation in the hippocampus. *Frontiers in Systems Neuroscience*, *7*, 74.

Rönnlund, M., Nyberg, L., Bäckman, L., and Nilsson, L. (2003). Recall of subject-performed tasks, verbal tasks, and cognitive activities across the adult life span: Parallel age-related deficits. *Aging Neuropsychology and Cognition*, *10*, 182–201.

Rose, N. S. and Craik, F. I. M. (2012). A processing approach to the working memory/long-term memory distinction: Evidence from the levels-of-processing span task. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *38*, 1019–1029.

Rose, N. S., Buchsbaum, B. R., and Craik, F. I. M. (2014). Short-term retention of a single word relies on retrieval from long-term memory when both rehearsal and refreshing are disrupted. *Memory & Cognition*, *42*, 689–700.

Rose, N. S., Craik, F. I. M., and Buchsbaum, B. R. (2015). Levels of processing in working memory: Differential involvement of fronto-temporal networks. *Journal of Cognitive Neuroscience*, *27*, 522–532.

Rosenzweig, M. R. (1994). Some surprising findings about memory and its biological bases. In: P. Bertelson, P. Eelen, and G. D'Ydewalle (Eds.), *International Perspectives on Psychological Science: Leading themes* (Vol. 1, pp. 1–24). Hove: Lawrence Erlbaum Associates.

Rowe, G., Valderrama, S., Hasher, L., and Lenartowicz, A. (2006). Attentional disregulation: A benefit for implicit memory. *Psychology and Aging*, *21*, 826–830. https://doi.org/10.1037/0882-7974.21.4.826

Ruchkin, D. S., Grafman, J., Cameron, K., and Berndt, R. S. (2003). Working memory retention systems: A state of activated long-term memory. *Behavioral and Brain Sciences*, *26*, 709–777. https://doi.org/10.1017/S0140525X03000165

Rugg, M. D. and Wilding, E. L. (2000). Retrieval processing and episodic memory. *Trends in Cognitive Sciences*, *4*, 108-115.

Rumelhart, D. E. (1977). Toward an interactive model of reading. In: S. Dornic (Ed.), *Attention and Performance, VI* (pp. 573–603). Hillsdale, NJ: Erlbaum.

Rundus, D. and Atkinson, R. C. (1970). Rehearsal processes in free recall: A procedure for direct observation. *Journal of Verbal Learning & Verbal Behavior*, *9*, 99–105. https://doi.org/10.1016/S0022-5371(70)80015-9

Salthouse, T. A. (1981). Converging evidence for information-processing stages: A comparative-influence stage-analysis method. *Acta Psychologica*, *47*, 39–61. https://doi.org/10.1016/0001-6918(81)90038-X

Salthouse, T. A. (1982). *Adult Cognition*. New York: Springer-Verlag.

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review*, *103*, 403–428.

Salthouse, T. A. (2010). Selective review of cognitive aging. *Journal of the International Neuropsychological Society*, *5*, 754–760.

Salthouse, T. A. and Babcock, R. L. (1991). Decomposing adult age differences in working memory. *Developmental Psychology*, *27*, 763–776. https://doi.org/10.1037/0012-1649.27.5.763

Saltz, E. and Donnenwerth-Nolan, S. (1981). Does motoric imagery facilitate memory for sentences? A selective interference test. *Journal of Verbal Learning & Verbal Behavior*, *20*, 322–332. doi: 10.1016/S0022-5371(81)90472-2.

Schacter, D. L. (1982). *Stranger Behind the Engram: Theories of Memory and the Psychology of Science*. Hillsdale, NJ: L. Erlbaum Associates.

Schacter, D. L. (1987). Implicit memory: History and current status. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *13*, 501–518. https://doi.org/10.1037/0278-7393.13.3.501

Schacter, D. L. and Church, B. A. (1992). Auditory priming: Implicit and explicit memory for words and voices. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*, 915–930. https://doi.org/10.1037/0278-7393.18.5.915

Schacter, D. L. and Tulving, E. (1994). What are the memory systems of 1994? In: D. L. Schacter and E. Tulving (Eds.), *Memory Systems 1994* (pp. 1–38). Cambridge, MA: The MIT Press.

Schacter, D. L., Harbluk, J. L., and McLachlan, D. R. (1984). Retrieval without recollection: An experimental analysis of source amnesia. *Journal of Verbal Learning & Verbal Behavior*, *23*, 593–611. https://doi.org/10.1016/S0022-5371(84)90373-6

Schacter, D. L., Norman, K. A., and Koutstaal, W. (1998). The cognitive neuroscience of constructive memory. *Annual Review of Psychology*, *49*, 289–318.

Schacter, D. L., Wagner, A. D., and Buckner, R. L. (2000). Memory systems of 1999. In: E. Tulving and F. I. M. Craik (Eds.), *The Oxford Handbook of Memory* (pp. 627–643). New York, NY: Oxford University Press.

Schlagman, S., Kliegel, M., Schulz, J., and Kvavilashvili, L. (2009). Differential effects of age on involuntary and voluntary autobiographical memory. *Psychology and Aging*, *24*, 397–411. doi: 10.1037/a0015785.

Schmiedek, F., Lövdén, M., and Lindenberger, U. (2014). A task is a task is a task: Putting complex span, n-back, and other working memory indicators in psychometric context. *Frontiers in Psychology*, *5*, 1–8. https://doi.org/10.3389/fpsyg.2014.01475

Schonfield, D. (1982). Attention switching in higher mental process. In: F. I. M. Craik & S. Trehub (Eds.), *Aging and Cognitive Processes* (pp. 309–316). New York, NY: Plenum Press.

Schonfield, D. and Robertson, B. A. (1966). Memory storage and aging. *Canadian Journal of Psychology*, *20*, 228–236.

Schulman, A. I. (1974). Memory for words recently classified. *Memory & Cognition*, *2*, 47–52. https://doi.org/10.3758/BF03197491

Scoville, W. B. and Milner, B. (1957). Loss of recent memory after bilateral hippocampal lesions. *Journal of Neurology, Neurosurgery & Psychiatry*, *20*(1), 11–21. doi: 10.1136/jnnp.20.1.11.

Scullin, M. K., McDaniel, M. A., and Shelton, J. T. (2013). The dynamic multiprocess framework: Evidence from prospective memory with contextual variability. *Cognitive Psychology*, *67*, 55–71. doi: 10.1016/j.cogpsych.2013.07.001.

Seamon, J. G. and Virostek, S. (1978). Memory performance and subject-defined depth of processing. *Memory & Cognition*, *6*(3), 283–287. doi: 10.3758/bf03197457.

Shah, P. and Miyake, A. (1996). The separability of working memory resources for spatial thinking and language processing: An individual differences approach. *Journal of Experimental Psychology: General*, *125*, 4–27. https://doi.org/10.1037/0096-3445.125.1.4

Shallice, T. (1982). Specific impairments of planning. *Philosophical Transactions of the Royal Society of London*, *298*, 199–209.

Shallice, T., Fletcher, P., Frith, C. D., et al. (1994). Brain regions associated with acquisition and retrieval of verbal episodic memory. *Nature*, *368*, 633–635. https://doi.org/10.1038/368633a0

Shaw, R. J. and Craik, F. I. M. (1989). Age differences in predictions and performance on a cued recall task. *Psychology and Aging*, *4*, 131–135.

Shepard, R. N. (1967). Recognition memory for words, sentences, and pictures. *Journal of Verbal Learning and Verbal Behavior*, *6*(1), 156–163.

Shiffrin, R. M. (1976). Capacity limitations in information processing, attention, and memory. In: W. K. Estes (Ed.), *Handbook of Learning and Cognitive Processes: Attention and Memory* (Vol. 4, pp. 177–236). Hillsdale, NJ: Erlbaum.

Shimamura, A. P. (1995). Memory and frontal lobe function. In: M. S. Gazzaniga (Ed.), *The Cognitive Neurosciences* (pp. 803–813). Cambridge, MA: MIT Press.

Simon, E. (1979). Depth and elaboration of processing in relation to age. *Journal of Experimental Psychology: Human Learning and Memory*, *5*, 115–124.

Skinner, E. I., Manios, M., Fugelsang, J., and Fernandes, M. A. (2014). Reinstatement of encoding context during recollection: behavioural and neuroimaging evidence of a double dissociation. *Behavioral Brain Research*, *264*, 51–63. doi: 10.1016/j.bbr.2014.01.033.

Slamecka, N. J. and Graf, P. (1978). The generation effect: Delineation of a phenomenon. *Journal of Experimental Psychology: Human Learning & Memory*, *4*, 592–604. doi: 10.1037//0278-7393.4.6.592.

Smallwood, J. and Schooler, J. W. (2006). The restless mind. *Psychological Bulletin*, *132*, 946–958. doi: 10.1037/0033-2909.132.6.946.

Smirnov, A. A. (1973). *Problems of the Psychology of Memory*. New York: Plenum Press.

Smith, R. E. (2006). Adult age differences in episodic memory: Item-specific, relational, and distinctive processing. In: R. R. Hunt and J. B. Worthen (Eds.), *Distinctiveness and Memory* (p. 259–287). New York: Oxford University Press.

Smith, R. E. (2017). Prospective memory in context. *Psychology of learning and motivation*, *66*, 211–249. doi: 10.1016/bs.plm.2016.11.003.

Squire, L. R. (1982). The neuropsychology of human memory. *Annual Review of Neuroscience*, *5*, 241–273. https://doi.org/10.1146/annurev.ne.05.030182.001325

Squire, L. R. (1987). *Memory and brain*. New York; Oxford University Press.

Squire, L. R. and Alvarez, P. (1995). Retrograde amnesia and memory consolidation: a neurobiological perspective. *Current Opinion in Neurobiology*, *5*, 169–177.

Squire, L. R., Genzel, L., Wixted, J. T., and Morris, R. G. (2015). Memory consolidation. *Cold Spring Harbor Perspectives in Biology*, *7*, a021766

Söderlund, H., Parker, E. S., Schwartz, B. L., and Tulving, E. (2005). Memory encoding and retrieval on the ascending and descending limbs of the blood alcohol concentration curve. *Psychopharmacology*, *182*, 305–317. https://doi.org/10.1007/s00213-005-0096-2

Spencer, W. D. and Raz, N. (1995). Differential effects of aging on memory for content and context: A meta-analysis. *Psychology and Aging*, *10*, 527–539.

Sperling, G. (1963). A model of visual memory tasks. *Human Factors*, *5*, 19–31.

Standing, L. (1973). Learning 10000 pictures. *Quarterly Journal of Experimental Psychology*, *25*, 207–222.

Staresina, B.P. and Wimber, M. (2019). A neural chronometry of memory recall. *Trends in Cognitive Sciences*, *23*, 1071–1085.

Sternberg, R. J. and Tulving, E. (1977). The measurement of subjective organization in free recall. *Psychological Bulletin*, *84*, 539–556.

St. Jacques, P. L., Kragel, P. A., and Rubin, D. C. (2011). Dynamic neural networks supporting memory retrieval. *NeuroImage*, *57*, 608–616. https://doi.org/10.1016/j.neuroimage.2011.04.039

St-Laurent, M., Abdi, H., Bondad, A., and Buchsbaum, B. R. (2014). Memory reactivation in healthy aging: evidence of stimulus-specific dedifferentiation. *The Journal of Neuroscience*, *34*, 4175–4186.

Stuss, D. T. (1991). Self, awareness, and the frontal lobes: A neuropsychological perspective. In: J. Strauss and G. R. Goethals (Eds.), *The Self: Interdisciplinary Approaches* (pp. 255-278). New York: Springer.

Stuss, D. T. and Alexander, M. P. (2007). Is there a dysexecutive syndrome? *Philosophical Transactions of the Royal Society of London, B, Biological Sciences*, *362*, 901–915.

Stuss, D. T. and Benson, D. F. (1986). *The Frontal Lobes*. New York: Raven Press.

Stuss, D. T. and Craik, F. I. M. (2020). Alterations in executive functions with aging. In: K. H. Heilman and S. E. Nadeau (Eds.), *Cognitive Changes and the Aging Brain* (pp. 168–187). New York, NY: Cambridge University Press.

Stuss, D. T. and Knight, R. T. (Eds.). (2002). *Principles of Frontal Lobe Function*. New York, NY: Oxford University Press.

Stuss, D. T., Craik, F. I. M., Sayer, L., et al. (1996). Comparison of elderly subjects to patients with frontal lesions: Evidence from word list learning. *Psychology and Aging*, 11, 387–395.

Svoboda, E., McKinnon, M. C., and Levine, B. (2006). The functional neuroanatomy of autobiographical memory: A meta-analysis. *Neuropsychologia*, *44*, 2189–2208.

Symons, C. S. and Johnson, B. T. (1997). The self-reference effect in memory: a meta-analysis. *Psychological Bulletin*, *121*, 371–394.

Swets, J. A., Tanner, W. P., and Birdsall, T. G. (1961). Decision processes in perception. *Psychological Review*, *68*, 301–340. doi: 10.1037/0033-295x.68.5.301.

Tardif, T. and Craik, F. I. M. (1989). Reading a week later: Perceptual and conceptual factors. *Journal of Memory and Language*, *28*, 107–125. doi: 10.1016/0749-596X(89)90031-4.

Taylor, M. M., Lindsay, P. M., and Forbes, S. M. (1967). Quantification of shared capacity processing. *Acta Psychologica*, *27*, 223–229.

Thapar, A., Ratcliff, R., and McKoon, G. (2003). A diffusion model analysis of the effects of aging on letter discrimination. *Psychology and Aging*, *18*, 415–429. https://doi.org/10.1037/0882-7974.18.3.415

Till, R. E. and Walsh, D. A. (1980). Encoding and retrieval factors in adult memory for implicational sentences. *Journal of Verbal Learning and Verbal Behavior*, *19*, 1–16.

Toth, J. P. (2000). Nonconscious forms of human memory. In: E. Tulving and F. I. M. Craik (Eds.), *The Oxford Handbook of Memory* (pp. 245–261). Oxford: Oxford University Press.

Treisman, A. M. (1960). Contextual cues in selective listening. *Quarterly Journal of Experimental Psychology*, *12*, 242–248. doi: 10.1080/17470216008416732.

Treisman, A. M. (1964a). Selective attention in man. *British Medical Bulletin*, *20*, 12–16. doi: 10.1093/oxfordjournals.bmb.a070274.

Treisman, A. M. (1964b). Verbal cues, language and meaning in selective attention. *American Journal of Psychology*, *77*, 206–219.

Treisman, A. M. (1964c). Monitoring and storage of irrelevant messages in selective attention. *Journal of Verbal Learning and Verbal Behavior*, *3*, 449–459.

Treisman, A. M. (1969). Strategies and models of selective attention. *Psychological Review*, *76*, 282–299.

Treisman, A. M. (1979). The psychological reality of levels of processing. In: L. S. Cermak and F. I. M. Craik (Eds.), Levels of Processing in Human Memory (pp. 301–330). Hillsdale, NJ: Lawrence Erlbaum Associates.

Troyer, A. K., Häfliger, A., Cadieux, M. J., and Craik, F. I. M. (2006). Name and face learning in older adults: The effects of level of processing, self-generation, and intention to learn. *Journal of Gerontology: Psychological Sciences*, *61B*, 67–74.

Tucker-Drob, E. M. (2009). Differentiation of cognitive abilities across the life span. *Developmental Psychology*, *45*, 1097–1118. https://doi.org/10.1037/a0015864

Tucker-Drob, E. M., Brandmaier, A. M., and Lindenberger, U. (2019). Coupled cognitive changes in adulthood: A meta-analysis. *Psychological Bulletin*, *145*, 273–301. https://doi.org/10.1037/bul0000179

Tuholski, S. W., Engle, R. W., and Baylis, G. C. (2001). Individual differences in working memory capacity and enumeration. *Memory & Cognition*, *29*, 484–492.

Tulving, E. (1962). Subjective organization in free recall of "unrelated" words. *Psychological Review*, *69*, 344–354. doi: 10.1037/h0043150.

Tulving, E. (1964). Intratrial and intertrial retention: Notes towards a theory of free recall verbal learning. *Psychological Review*, *71*, 219–237. doi: 10.1037/h0043186.

Tulving, E. (1967). The effects of presentation and recall of material in free-recall learning. *Journal of Verbal Learning and Verbal Behavior*, *6*, 175–184.

Tulving, E. (1968). Theoretical issues in free recall. In: T. R. Dixon and D. L. Horton (Eds.), *Verbal Behavior and General Behavior Theory* (pp. 2-36). Upper Saddle River, NJ: Prentice-Hall

Tulving, E. (1974). Cue-dependent forgetting. *American Scientist*, *62*, 74–82.

Tulving, E. (1982). Synergistic ecphory in recall and recognition. *Canadian Journal of Psychology/Revue canadienne de psychologie*, *36*, 130–147. doi: 10.1037/h0080641.

Tulving, E. (1983). *Elements of Episodic Memory*. Oxford: Oxford University Press.

Tulving, E. (1985). Memory and consciousness. *Canadian Psychology/Psychologie canadienne*, *26*, 1–12. https://doi.org/10.1037/h0080017

Tulving, E. (2001). Does memory encoding exist? In: M. Naveh-Benjamin, M. Moscovitch, and H. L. Roediger, III (Eds.), *Perspectives on Human Memory and Cognitive Aging: Essays in Honour of Fergus Craik* (pp. 6–27). Philadelphia, PA: Psychology Press.

Tulving, E. and Colotla, V. (1970). Free recall of trilingual lists. *Cognitive Psychology*, 1, 86–98.

Tulving, E. and Madigan, S. A. (1970). Memory and verbal learning. *Annual Review of Psychology*, *21*, 437–484. doi: 10.1146/annurev.ps.21.020170.002253.

Tulving, E. and Pearlstone, Z. (1966). Availability versus accessibility of information in memory for words. *Journal of Verbal Learning & Verbal Behavior*, *5*, 381–391. doi: 10.1016/S0022-5371(66)80048-8.

Tulving, E. and Schacter, D. L. (1990). Priming and human memory systems. *Science*, *247*, 301–306.

Tulving, E. and Thomson, D. M. (1973). Encoding specificity and retrieval processes in episodic memory. *Psychological Review*, *80*, 352–373. doi: 10.1037/h0020071.

Tulving, E., Kapur, S., Craik, F. I. M., Moscovitch, M., and Houle, S. (1994). Hemispheric encoding/retrieval asymmetry in episodic memory: Positron emission tomography findings. *Proceedings of the National Academy of Sciences of the USA*, *91*, 2016–2020.

Tulving, E., Markowitsch, H. J., Craik, F. I. M., Habib, R., and Houle, S. (1996). Novelty and familiarity activations in PET studies of memory encoding and retrieval. *Cerebral Cortex*, *6*, 71–79. https://doi.org/10.1093/cercor/6.1.71

Tulving, E., Schacter, D. L., and Stark, H. A. (1982). Priming effects in word-fragment completion are independent of recognition memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *8*, 336–342. doi: 10.1037/0278-7393.8.4.336.

Turner, M. L. and Engle, R. W. (1989). Is working memory capacity task dependent? *Journal of Memory and Language*, *28*, 127–154. https://doi.org/10.1016/0749-596X(89)90040-5

Turvey, M. T., Shaw, R. E., and Mace, W. M. (1978). Issues in the theory of action: Degrees of freedom, coordinative structures and coalitions. In: J. Requin (Ed.), *Attention and performance VII* (pp. 557–595). Hillsdale, NJ: Erlbaum.

Tversky, A. and Kahneman, D. (1973). Availability: A heuristic for judging frequency and probability. *Cognitive Psychology*, *5*, 207–232. doi: 10.1016/0010-0285(73)90033-9.

Unsworth, N. and Engle, R. W. (2007). The nature of individual differences in working memory capacity: Active maintenance in primary memory and controlled search from secondary memory. *Psychological Review*, *114*, 104–132. doi: 10.1037/0033-295x.114.1.104.

Unsworth, N. and Robison, M. K. (2017). A locus coeruleus-norepinephrine account of individual differences in working memory capacity and attention control. *Psychonomic Bulletin & Review*, *24*, 1282–1311.

van Dongen, E. V., Kersten, I. H. P., Wagner, I. C., Morris, R. G. M., and Fernandez, G. (2016). Physical exercise performed four hours after learning improves memory retention and increases hippocampal pattern similarity during retrieval. *Current Biology*, *26*, 1722–1727. doi: 10.1016/j.cub.2016.04.071.

Varela, F. J., Thompson, E., and Rosch, E. (1991). *The Embodied Mind: Cognitive Science and Human Experience*. Cambridge, MA: MIT Press.

Velichkovsky, B. M. (2001). Levels of processing: Validating the concept. In: M. Naveh-Benjamin, M. Moscovitch, and H. L. Roediger III (Eds.), *Perspectives on Human Memory and Cognitive Aging: Essays in Honour of Fergus Craik* (pp. 48–70). New York: Psychology Press.

Velichkovsky, B. M. (2002). Heterarchy of cognition: The depth and the highs of a framework for memory. *Memory*, 10, 405–419.

Vygotsky, L. S. (1978). *Mind in Society: The Development of Higher Psychological Processes*. Cambridge, MA: Harvard University Press.

Wagner, A. D. and Gabrieli, J. D. (1998). On the relationship between recognition familiarity and perceptual fluency: Evidence for distinct mnemonic processes. *Acta Psychologica*, *98*, 211–230. doi: 10.1016/s0001-6918(97)00043-7.

Walsh, D. A. and Jenkins, J. J. (1973). Effects of orienting tasks on free recall in incidental learning: “Difficulty,” “effort,” and “process” explanations. *Journal of Verbal Learning and Verbal Behavior*, *12*, 481–488. doi: 10.1016/S0022-5371(73)80028-3.

Wang, M., Gamo, N. J., Yang, Y., et al. (2011). Neuronal basis of age-related working memory decline. *Nature*, *476*, 210–213.

Warrington, E. K. and Shallice, T. (1969). The selective impairment of auditory verbal short-term memory. *Brain: A Journal of Neurology*, *92*, 885–896. https://doi.org/10.1093/brain/92.4.885

Watkins, M. J. (1977). The intricacy of memory span. *Memory & Cognition*, *5*, 529–534. https://doi.org/10.3758/BF03197396

Watkins, M. J. (2001). Part I Introduction: Levels of Processing. In: M. Naveh-Benjamin, M. Moscovitch, and H. L. Roediger III (Eds.), *Perspectives on Human Memory and Cognitive Aging*: *Essays in Honour of Fergus Craik*. (pp. 3–5). New York, NY: Psychology Press.

Watkins, M. J. and Watkins, O. C. (1974a). Processing of recency items for free recall. *Journal of Experimental Psychology*, *102*, 488–493. https://doi.org/10.1037/h0035903

Watkins, M. J. and Watkins, O. C. (1974b). A tactile suffix effect. *Memory & Cognition*, *2*, 176–180. doi: 10.3758/bf03197511.

Watkins, O. C. and Watkins, M. J. (1975). Buildup of proactive inhibition as a cue overload effect. *Journal of Experimental Psychology: Human Learning and Memory*, *1*, 442–452.

Waugh, N. C. and Norman, D. A. (1965). Primary memory. *Psychological Review*, *72*(2), 89–104. doi: 10.1037/h0021797.

Weldon, M. S. and Roediger, H. L. (1987). Altering retrieval demands reverses the picture superiority effect. *Memory & Cognition*, *15*, 269–280.

Welford, A. (1958). *Ageing and Human Skill*. London: Oxford University Press.

Wertsch, J. V. (1981). *Trends in Soviet Cognitive Psychology*. Bologna: Società editrice il Mulino.

Wertsch, J. V. (1991). A sociocultural approach to socially shared cognition. In: L. B. Resnick, J. M. Levine, and S. D. Teasley (Eds.), *Perspectives on Socially Shared Cognition* (pp. 85–100). Washington, DC: American Psychological Association.

West, R. (1999). Age differences in lapses of intention in the Stroop task. *The Journals of Gerontology: Series B*, *54B*, P34–P43. doi: 10.1093/geronb/54B.1.P34.

West, R. and Craik, F. I. M. (1999). Age-related decline in prospective memory: The roles of cue accessibility and cue sensitivity. *Psychology and Aging*, *14*, 264–272.

Westerhausen, R., Moosmann, M., Alho, K., et al. (2010). Identification of attention and cognitive control networks in a parametric auditory fMRI study. *Neuropsychologia*, *48*, 2075–2081.

Wheeler, M. E., Petersen, S. E., and Buckner, R. L. (2000). Memory's echo: Vivid remembering reactivates sensory-specific cortex. *Proceedings of the National Academy of Sciences*, *97*, 11125–11129. doi: 10.1073/pnas.97.20.11125.

Whitten, W. B. (1978). Initial-retrieval "depth" and the negative recency effect. *Memory & Cognition*, *6*, 590–598. https://doi.org/10.3758/BF03198248

Wickens, D. D. (1970). Encoding categories of words: An empirical approach to meaning. *Psychological Review*, *77*, 1–15. https://doi.org/10.1037/h0028569

Wickens, D. D. (1973). Some characteristics of word encoding. *Memory & Cognition*, *1*, 485–490. https://doi.org/10.3758/BF03208913

Wiggs, C. L. and Martin, A. (1998). Properties and mechanisms of perceptual priming. *Current Opinion in Neurobiology*, *8*, 227–233.

Williams, J. M. G., Barnhofer, T., Crane, C., et al. (2007). Autobiographical memory specificity and emotional disorder. *Psychological Bulletin*, *133*, 122–148. doi: 10.1037/0033-2909.133.1.122.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review*, *9*(4), 625–636. doi: 10.3758/bf03196322.

Winthorpe, C. and Rabbitt, P. M. A. (1988). Working memory capacity, IQ, age and the ability to recount autobiographical events. In: M. M. Gruneberg, P. E. Morris, and R. N.

Sykes (Eds.), *Practical Aspects of Memory: Current Research and Issues* (Vol. 2, pp. 175–179). Chichester: John Wiley.

Witherspoon, D. and Allan, L. G. (1985). The effect of a prior presentation on temporal judgements in a perceptual identification task. *Memory & Cognition*, *13*, 101–111.

Woodward, A. E., Bjork, R. A., and Jongeward, R. H. (1973). Recall and recognition as a function of primary rehearsal. *Journal of Verbal Learning and Verbal Behavior*, *12*, 608–617. doi: 10.1016/s0022-5371(73)80040-4.

Woodworth, R. S. (1929). *Psychology: A Science of Mental Life*. New York, NY: Henry Holt.

Yonelinas, A. P., Ranganath, C., Ekstrom, A. D., and Wiltgen, B. J. (2019). A contextual binding theory of episodic memory: Systems consolidation reconsidered. *Nature Reviews Neuroscience*, *20*, 364–375.

Zimmer, H. D., Cohen, R. L., Guynn, M. J., et al. (2001). *Memory for Action: A Distinct Form of Episodic Memory?* Oxford: Oxford University Press.

Zimmer, H. D. and Engelkamp, J. (1999). Levels-of-processing effects in subject-performed tasks. *Memory & Cognition*, *27*, 907–914.

Zola, S. M. and Squire, L. R. (2000). The medial temporal lobe and the hippocampus. In: E. Tulving and F. I. M. Craik (Eds.), *The Oxford Handbook of Memory* (pp. 485–500). New York, NY: Oxford University Press.

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