Nobuo Ohta, Colin M. MacLeod, Bob Uttl (Eds.)

Dynamic Cognitive Processes

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With 85 Figures, Including 3 in Color

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Cover: Design image by Bob Uttl and Amy Siegenthaler. The Mandelbrot fractal's inherently dynamic nature is an apt metaphor for the theme of dynamic cognitive processes.

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Preface

The conference from which this book derives took place in Tsukuba, Japan in March 2004. The fifth in a continuing series of conferences, this one was organized to examine dynamic processes in "lower order" cognition from perception to attention to memory, considering both the behavioral and the neural levels. We were fortunate to attract a terrific group of contributors representing five countries, which resulted in an exciting conference and, as the reader will quickly discover, an excellent set of chapters. In Chapter 1, we will provide a sketchy "road map" to these chapters, elucidating some of the themes that emerged at the conference.

The conference itself was wonderful. We very much enjoyed the variety of viewpoints and issues that we all had the opportunity to grapple with. There were lively and spirited exchanges, and many chances to talk to each other about exciting new research, precisely what a good conference should promote. We hope that the readers of this book will have the same experience—moving from careful experimental designs in the cognitive laboratory to neural mechanisms measured by new technologies, from the laboratory to the emergency room, from perceptual learning to changes in memory over decades, all the while squarely focusing on how best to explain cognition, not simply to measure it. Ultimately, the goal of science is, of course, explanation. We also hope that the reader will come away absolutely convinced that cognition is a thoroughly dynamic, interactive system.

Conference organizers develop a conference, but it is everyone else who makes it a real success. We therefore have a number of agencies and people to thank, and it is our pleasure to do so. First, we thank the Japanese Ministry of Education and Sciences for providing the funding and the University of Tsukuba for providing a very welcoming and comfortable setting. We are, of course, grateful to the stellar line-up of speakers who made the conference exciting and who also contributed stimulating chapters to this book. We thank Amy Siegenthaler for her dedicated editorial assistance, and Springer-Verlag (Tokyo) for publishing this book. Most of all, we thank the Japanese cognitive psychology community for its enthusiastic participation. It is good to know that not only cognition itself but also the cognitive community is dynamic!

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Dynamic Cognitive Processes in Broad Perspective

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Summary. This brief chapter provides an overview of the book. A sketch is provided of the sharp contrast between the popular view that cognition is relatively static and the view in the discipline that cognition is highly dynamic. This provides the high-level theme of the entire book. Weaving throughout the book are several other more specific themes, notably the roles of consciousness and of inhibition in cognition, and the complimentary behavioural and neuroscience approaches. Linkages across chapters are described, and a brief synopsis of each chapter is provided.

Keywords. Dynamic cognition, static cognition, perception, attention, memory.

Introduction

In the "real world"—which cognitive psychologists resolutely insist on thinking they are part of—it is widely believed that the apparatus of cognition is static. This has been true for millennia, perhaps the result of (or at least a reflection of) Plato's powerful "wax tablet" metaphor conjuring an image of a fixed memory. Eyewitness reports in the courtroom serve as the quintessential example. Eyewitnesses have seen the episode with their "own eyes," so police, jurors, and judges place heavy reliance on their "first hand" descriptions and recountings of the event. Perception is seen as literal, as if done by an audio/video recording device: What happened is precisely what the eyewitness saw and heard at that moment in time. Attention is seen as automatic, captured in a thoroughly consistent way by the event: What happened was the focus of the eyewitness's experience, shared with other eyewitnesses. Memory is seen as composed of faithful records of the event as if captured on videotape; they may fade but they do not change over time: What the eyewitness reports from memory later is exactly what they experienced at the time of the original event, which in turn is exactly what happened.

Cognitive psychologists know that this perspective is wrong. Indeed, it would be considerably closer to the truth to say that this perspective is wholly wrong than wholly right. We have known this for a long time, perhaps since the very beginnings of psychology in the late 1800s, and we continue to reinforce and elaborate on just how wrong this view is, as our understanding of cognition broadens and deepens.

The cognitive revolution that began a half century ago has, in fact, been very much about the realization of how sweepingly non-static cognition really is. This is strikingly clear in the book that became the "manifesto" of cognitive psychology: Ulric Neisser's *Cognitive Psychology* (1967). On the first page of the introduction, Neisser emphasizes that thought always influences cognition, saying that "Whatever we know about reality has been *mediated*, not only by the organs of sense but by complex systems which interpret and reinterpret sensory information" (p. 3). A few pages later, he brings forth the key idea, saying that "The central assertion is that seeing, hearing, and remembering are all acts of *construction*, which may make more or less use of stimulus information depending on circumstances" (p. 10).

The highly dynamic framework set out by Neisser continues to be the guiding perspective of cognitive psychologists, and explains why we stand apart from everyone else in how we understand the world around us. Dynamic cognition permits flexible interaction with our environment, allowing us to exert "cognitive control" over our experience. We are not passive recipients of information but active manipulators of it.

It might reasonably be said that, after a half century, it is a little discouraging that our dynamic perspective has not overcome the dominant static perspective "out there."[1] But change of this grand scope is rarely rapid, and inroads have been made. Indeed, the best illustration of a change in everyday thinking about cognition is with respect to the very example described above: eyewitness testimony. The pioneering research of Elizabeth Loftus (1979; Loftus & Ketcham, 1991) and the continuing work of many other cognitive researchers have fostered recognition in the legal community of the fallibility of eyewitness testimony because of the dynamic, reconstructive nature of the cognition upon which that testimony rests. As another illustration, the burgeoning literature on false memories (see, e.g., Schacter, 1995; 2001), where we create in our minds episodes

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[1] In fact, this fundamental idea of cognition being constructive goes back much earlier, at least to the work of Bartlett (1932) on memory, amazingly done at the height of behaviorism, which itself took a decidedly more static perspective.

that did not actually happen yet we confidently believe them to have happened, attests further to the pervasive dynamics of cognition.

A Survey of the Book

The chapters in this book provide evidence of how very dynamic cognition is. They represent "state of the art" descriptions of research programs covering the range from perception to memory. They also illustrate the breadth of the approaches and methodologies being used to reveal cognitive processes, from behavioral studies to brain imaging. Our goal in this first chapter is to guide the reader through the organization of the book, to give a sense of the emphasis of each chapter, and to highlight some of the principal themes that cut across the chapters.

Beginning our travels at the beginning, in the domain of perception, Behrmann, Geng, and Baker pose a question that has been recognized as fundamental since the earliest philosophers began to think about the mind: How do we develop a usable percept, given the overwhelming complexity of the world around us? In showing that there are a great many processes involved, they make abundantly clear the degree to which multiple stages of interpretation are always ongoing. Yet out of this comes a powerful form of learning, one of which we are ordinarily not even aware. This issue of awareness or consciousness also becomes one of the principal themes of the book, foreshadowing chapters by Merikle and Smith; Rajaram and Travers; Otani, Kato, and Widner, and others. The elegance of the converging approach that Behrmann, Geng, and Baker use—examining normal and patient populations as well as non-human animals, and delving into the behavioral and the neural levels of analysis—provides a kind of "case study" of what is best about cognitive neuroscience. Coming full circle, the book also closes with a chapter by Moscovitch and his colleagues also focusing on the brain-cognition linkage. Not only is cognition dynamic, but so are the neural processes upon which cognition operates.

Continuing to focus on perception, but more at the level of experience, Toppino and Long take what might seem to be a very simple—and hence simply explained—perceptual phenomenon and show its cognitive complexity. They examine one of the best known of all visual illusions—the Necker cube—and in a series of simple yet powerful experiments demonstrate that the resonance between the two ways to see the figure is due neither to bottom up nor to top down processes, but to both operating in concert. The interplay between the two types of processing is fundamentally dynamic: We are constructing our perceptions, not simply having them wash over us. That this is true for a simple line drawing should immediately make clear that cognition is vastly more complex and malleable than a static view could ever hope to explain. Cognitive processes "talk to each other" and through this conversation we develop an understanding of our world in all its complex interaction.

Moving to the realm of attention, Humphreys, Braithwaite, Olivers, and Watson describe a clever technique for investigating the nature of search processes involved in visual attention. What happens to our processing of a visual scene when part of the display that we must search through is "previewed"? What if the previewed part does not contain what we are looking for? The clear answer at the gross level is that we benefit, sometimes as if that previewed portion can be entirely set aside and consequently not interfere with searching the rest. The preview is very brief in these studies, yet we can rapidly avail ourselves of this information and change the way we deal with the entire display. This flexibility is the hallmark of dynamic information processing. Like Behrmann et al. and also Moscovitch et al., Humpreys et al. relate their findings to the neural underpinnings of perception and attention, reflecting the ever-increasing merging of cognitive and neurophysiological approaches. Moreover, their account of how we disregard the previewed information rests on our inhibiting that information; clearly, this inhibition is viewed as an important part of our ability to attend selectively, a fundamental element of cognitive control. By introducing the concept of inhibition here, Humphreys et al. also establish one of the major themes of this conference, as will become evident when we consider some of the chapters on memory by Whittlesea and Hughes; Anderson; Rajaram and Travers; and Sheard and MacLeod.

Merikle and Smith provide a bridge from the perception and attention chapters to those on memory. They tackle a problem that was long neglected in the study of cognition, and even seen as impossible to study—consciousness. Over the past quarter century, though, there has been a dramatic change in this view, both in attention and memory, and indeed elsewhere in psychology. Consciousness research, in one form or another, now abounds. This is certainly in keeping with the dynamic perspective, and even broadens it to include dramatic processing below awareness. Again, a simple question becomes the basis for an elegant series of studies: How long does information acquired beneath the level of consciousness persist in memory and influence our behavior? Their answer is that such information may last a very long time, and again the beauty of a converging approach is ably demonstrated. They show this via their own careful experiments, via a meta-analysis of relevant literature, and via research on anaesthetized patients, finding all of these kinds of research to point to the same conclusion: that unconsciously perceived information leaves a quite deep and lasting footprint in memory. In so doing, they amplify one of the central themes of the conference—the role of consciousness in cognition. There would definitely appear to be dynamic processes operating not only above but also beneath the surface of consciousness.

Like Merikle and Smith, Whittlesea and Hughes write about research at the interface between perception/attention and memory. The phenomenon they study is itself evidence that we do not simply see precisely what is "out there." *Repetition blindness* refers to our failure to detect the reoccurrence of a stimulus in a rapid, but quite brief, stream of stimuli. Why would we fail to detect such a repetition? There are theories that ascribe this failure to inhibition of the repeated item's representation, again raising the inhibition theme that began here with Humphreys et al. Whittlesea and Hughes, however, present evidence that calls such an inhibitory explanation into question. Indeed, they argue strongly against such an activation/inhibition account more broadly in the realm of memory. They characterize such an explanation as far too static and opt instead for an account in terms of construction and attribution, which they argue to be optimally dynamic. The world around us is uncertain, and we must rapidly resolve that uncertainty to know how to function. To do so, we construct plausible interpretations on line from the information available in the world and in memory, and then we attribute our experience to the stimulus (or its facsimile in memory) rather than to our interpretation. Under this view, perception and memory are highly dynamic, piecing together "on the fly" a believable story about experience.

Starting from a very different perspective, Terasawa nevertheless arrives at a similar conclusion. He introduces a model of perception and memory that effectively adds what he refers to as *cross-inhibition* to existing large-scale memory models such as Hintzman's MINERVA2. He asks whether memory is retrieved or created, and suggests based on his model that "created" provides a better answer. Memories are in essence created on line as an outcome of multiple related retrievals. Of course, this answer is consistent with a more dynamic overall perspective on perception and memory. He maintains that remembering derives from activation of multiple non-symbolic representations and simultaneous "inter-restraint" (inhibition) of other representations. Out of this a coherent picture emerges, echoing in a more formal model the construct-and-attribute view that Whittlesea and Hughes put forward in the preceding chapter. Attempting to capture the dynamic nature of cognition in a structured, formal model is indeed an important challenge.

The inhibition theme moves front and center in the work of Anderson, as the book shifts its focus to memory. For a decade, Anderson has built the strongest case yet made for an important role of inhibition in memory.

He maintains that to control memory we must inhibit certain information to highlight other information. This permits behavior, and especially responding, to be flexible to the shifting constraints imposed by the environment. The proposed interplay between inhibition and activation is inherently a dynamic one, but the core of his argument is that inhibition is necessary for executive control—of memory, and indeed of behavior more generally. His experiments are clever and compelling. Most notable is his demonstration that a piece of information inhibited for one purpose may well carry that inhibition with it when it must be used for other, apparently unrelated purposes. In closing his chapter, Anderson makes contact with a number of the other memory situations where inhibition has been seen as playing a crucial role, leading nicely into the two chapters that follow his. And he also reports tantalizing new results suggestive of the localization of inhibitory processing using functional magnetic resonance imaging (fMRI), emphasizing again the cognitive neuroscience theme that runs throughout the chapters of this book.

The inhibition theme is further expanded on by Rajaram and Travers, in discussing what they refer to as "deselection"—a type of negative priming or inhibition that serves the purpose of de-emphasizing certain information in the environment so that other information may be accentuated. They investigate the relative effects of deselection on explicit and implicit tests of memory, where divided attention at encoding has been shown to reduce performance. In putting the emphasis on implicit memory, they return indirectly to the theme of consciousness discussed earlier by Merikle and Smith, given that implicit memory constitutes the use of memory without awareness. They then provide evidence that they see as warranting a long-lasting inhibitory influence. Like Anderson—but in sharp contrast to Whittlesea and Hughes—their overall perspective is that facilitation and inhibition work in tandem to handle the attentional and memorial demands of everyday information processing. Indeed, long-term memory is seen as resulting from the dynamic interaction of these two types of processes.

Sheard and MacLeod take a position much more akin to that of Whittlesea and Hughes than to those of Anderson and of Rajaram and Travers. The issue addressed by Sheard and MacLeod is how we update memory, and they use intentional forgetting—as realized in the *directed forgetting* paradigm—to address this issue. Of course, the very fact that we can update memory—that we can replace an old address with a new one or substitute a revised plan for its predecessor—is evidence of the malleability of learning and memory, and hence of the dynamic nature of processing. In directed forgetting, people are asked to forget specified information on cue, and do so with some success. One account of this has been that we inhibit what we want to forget; another has been that we selectively rehearse what we want to remember. Interestingly, the evidence for these two accounts comes from different instantiations of the directed forgetting paradigm. Sheard and MacLeod present data in support of the rehearsal explanation, and argue strongly that inhibition is not necessary to explain any instance of directed forgetting, again piquing the debate on inhibition.

Staying in the domain of memory, Otani, Kato, and Widner examine in detail a phenomenon that most people would probably think could never happen—improved memory over time without further opportunity to learn. This is called *hypermnesia*, which occurs when *intertest forgetting*, the loss of information that occurs quite intuitively with the passage of time, is outweighed by *reminiscence*, the additional recovery of information that can occur due to repeated testing. Their central question is whether reminiscence is conscious or unconscious, again returning to another of the central themes of the conference, discussed already by Merikle and Smith and by Rajaram and Travers. Covering a careful series of studies, they conclude that indeed reminiscence can be implicit, corresponding to the "real world" experience of information just "popping into mind." Something is happening in memory without further learning or even awareness, that leads to improved remembering, clear evidence of the fluctuating and dynamic nature of memory.

For much of the history of memory research, emphasis has been placed almost exclusively on memory for the past—*retrospective* memory. This bias makes sense: When we talk about remembering, this is what we ordinarily mean. But we also need to remember the future—*prospective* memory, and often find this type of remembering to be especially error-prone. The dentist appointment to go to, the medication to be taken—these intentions must also be encoded and retrieved. But until quite recently this form of remembering had received scant attention in the memory literature. [This may explain why retrograde amnesia seems so much more "intuitive" to people despite the fact that anterograde amnesia is the more common type—again, the natural bias is to associate memory with the past rather than the future.] Unlike the preceding chapters which were concerned with retrospective remembering, the next two chapters, by Uttl and by Graf, place prospective remembering front and center.

The issue of awareness—consciousness—is relevant here again, as prospective remembering requires awareness of our prior intention(s). Uttl considers how prospective and retrospective memory relate to each other, and examines the changes in these abilities with age. As well, he offers a cogent criticism of methods used to evaluate and measure prospective remembering. He also introduces a new paradigm for examining prospective memory, with the research using this paradigm leading him to conclude that decline with age is a function of reductions in both sensory abilities and processing resources. Graf puts forward an incongruity search hypothesis, which maintains that the initial processing done with respect to a prospective memory cue means that when retrieval occurs later, this cue generates a mismatch between anticipated and experienced fluency which leads in turn to a more concerted search. This kind of fluency and attribution idea harks back to the type of processing proposed by Whittlesea and Hughes in their chapter. Once again, we see on-line evaluation operating in remembering in very dynamic fashion. Indeed, to use prospective memory, we must dynamically recover our intentions while we are engaged in the ongoing flow of information processing.

In the final chapter, Moscovitch and his colleagues examine memory retrieval and consolidation from a broad and converging perspective, similar to that taken by Behrmann, Geng, and Baker at the beginning of the book, and thereby bringing us full circle. Moscovitch et al. explore the retrieval of autobiographical and other types of memories as a way to evaluate the process of consolidation. In the standard consolidation theory, hippocampal activity for a memory is held to decline over time, eventually "dropping out" as the memory is consolidated neocortically. Moscovitch et al. outline an alternative theory that they call *multiple trace theory* under which hippocampal activity does not disappear over time for autobiographical memories. They then describe tantalizing evidence from their own work and that of others to support this novel perspective. These fascinating ideas derive from converging work with normal individuals and amnesic individuals. This chapter is a wonderful place to end the book, illustrating as it does the richly dynamic interconnections in behavior and in brain that permit the successful functioning of cognition despite involving so many kinds of environmental (and mental) stimulation.

Conclusion

We hope that this brief sketch will serve to encourage the reader to delve into the many experimental and especially theoretical ideas brought forth by the authors, and to consider the new perspectives that they raise with respect to inhibition, consciousness, cognitive neuroscience, and the other themes that we have noted in this introduction. Taken as a collection, these chapters provide irrefutable evidence of the dynamic nature of cognition from perception to memory.

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Acquisition of Long-Term Visual Representations: Psychological and Neural Mechanisms

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Summary. How do we so rapidly achieve an organized, coherent visual percept of our superficially chaotic world? One way of reducing the complexity of the input is to take advantage of the statistical regularities and regular co-occurrences between aspects of objects and between objects and their spatial locations. In this chapter, converging data obtained from normal and brain-damaged individuals, as well as from single unit recording studies in monkeys, are presented, all of which address the psychological and neural mechanisms associated with statistical learning. The first section deals with learning regularities associated with particular spatial locations, presumably a function of the dorsal 'where' stream and data from normal individuals and from patients with hemispatial neglect are presented. The second section reports the findings from human and monkey studies, which show how statistical contingencies of the visual environment are reflected in behavior and how neurons in monkey inferotemporal cortex, the ventral "what" stream, appear to mediate these statistical effects. Taken together, using data from a variety of methodologies, this work attests to the flexibility and robustness of the visual system and sheds light on the way in which perceptual organization operates to convert raw input into long-term visual representations.

Key words. Vision, perceptual organization, visual learning, neuropsychology, agnosia, neurophysiology

Introduction

It is well established that human observers can learn statistically or probabilistically defined patterns (e.g., frequent co-occurrence) of both auditory stimuli (Saffran, Aslin, & Newport, 1996; Saffran, Johnson, Aslin, & Newport, 1999) and visual stimuli (Chun, 2002; Edelman, Hiles, Yang, &

Intrator, 2002; Fiser & Aslin, 2001, 2002a). It is also the case that humans are sensitive to spatial regularities in the environment and are able to exploit the statistical contingencies that determine the location of a visual target (Chun & Jiang, 1998; Hoffman & Kunde, 1999; Lewicki, Czyzewska, & Hoffman, 1987; Maljkovic & Nakayama, 1996; Mayr, 1996). Such learning, often called "statistical learning," is commonly described as incidental or implicit, in that learning of new representations can occur automatically without instruction and without observers explicitly attending to and encoding the patterns. For example, statistical learning has been demonstrated both when the stimuli are presented passively to observers in the absence of any explicit task (Fiser & Aslin, 2001), and when observers are attending to and performing a separate, unrelated task (Saffran, Newport, Aslin, Tunick, & Barrueco, 1997). Indeed, even if participants demonstrate no explicit awareness of the relation between targets and distractor context, they nevertheless respond faster to a visual target that appears in a repeated distractor configuration compared to one that appears in a novel configuration (Chun & Jiang, 1998).

Statistical learning is so ubiquitous that it has also been observed in human infants 9 months old or younger (Fiser & Aslin, 2002b; Kirkham, Slemmer, & Johnson, 2002; Saffran et al., 1996) as well as in naïve nonhuman primates (Baker, Behrmann, & Olson, 2002; Hauser, Newport, & Aslin, 2001). For example, one might think of the A-not-B error exhibited by infants—looking in the location where the previous stimulus appeared rather than in the location of the current stimulus—as an inability to inhibit the most probabilistic response associated with reward. But Smith, Thelen, Titzer, and McLin (1999) have argued that this type of error is caused by a directional bias in motor planning due in part to the history of looking and reaching to the A location during the preceding trial(s). Because infants have immature control systems, a brief visual input signaling the current B location is too weak to overcome the motor bias. However, if the visual stimulus at B is salient, it can pull the motor response toward that location (Smith et al., 1999). This suggests that whereas mechanisms supporting simple matching behaviors may be modulated by spatial orientation, they may also operate independently.

Indeed, the ability to track statistical probabilities linking behavior to reward appears to be widespread in animal species. The *matching law* characterizes the absolute rate of response as a linear function of the frequency of reinforcement. In one of the earliest examples, Herrnstein (1961) demonstrated that the frequency with which pigeons pecked at each of two response keys was commensurate with the reinforcement schedule at each key. Although different reinforcement paradigms result in under- or over-matching, the ranking of responses in correspondence with the available reinforcement hierarchy is well established (Baum, 1979; Greggers & Mauelshagen, 1997).

The central question is what psychological and neural mechanisms mediate statistical learning and, specifically, for the current purposes, visual statistical learning? This chapter examines this issue by reviewing a series of recent studies we have done addressing both learning of spatial regularities and learning of shape regularities in the visual modality. Each of the two sets of studies tracks the acquisition of these regularities in one of the two visual cortical streams, with the former set associated with parietal cortex and the latter with temporal cortex. In the course of conducting these studies, we have exploited a range of methodologies, including psychophysical studies with normal participants, behavioral investigations with individuals who have sustained brain damage, and single unit recording studies in awake, behaving monkeys. Through this convergence of methods, our goal is to elucidate the processes whereby visual representations are acquired as a function of the statistics of the input.

Learning and acquisition of spatial regularities

As alluded to previously, studies with humans and animals have shown that the sensitivity to the spatial location of a stimulus is contingent on the regularities in the input; for example, people respond faster to targets that appeared in the same distractor configuration compared to those that appear in novel configurations (Chun & Jiang, 1998). In fact, people appear to be sensitive to repetitions in target location over approximately 5-8 intervening trials even when there is no probability manipulation (Maljkovic & Nakayama, 1996). These findings are consistent with prior data suggesting that probabilistic distributions in target location are related to performance optimization (Shaw & Shaw, 1977).

Taken together, the results from human and nonhuman species implicate an evolutionarily primitive mechanism that is sensitive to environmental regularities that result in behavioral success. To explore this behavioral sensitivity further, we have conducted studies examining whether adult human participants match their behaviors to implicit regularities in target location during a visual search task (Geng & Behrmann, 2002). In particular, we (Joy Geng and Marlene Behrmann) were interested in investigating whether, in a visual search task, target discrimination is facilitated when targets are more likely to appear in locations on one half of the display compared to the other half of the display. This issue was investigated both in normal individuals and in patients with hemispatial neglect.

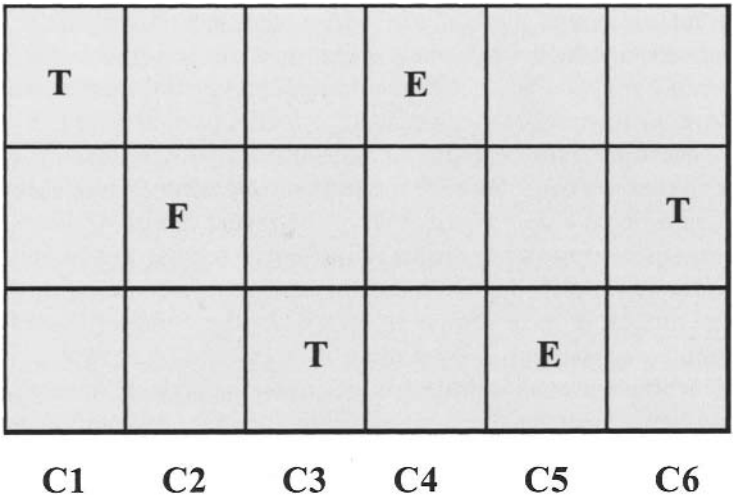

Fig. 1. Schematic depiction of the visual search display used to investigate facilitation of spatial regularities on target discrimination. Note that the grid was not visible to the participants; it is shown here for purposes of illustration. Six columns and three rows were used. Six stimuli appeared on each trial, a target and five distractors. The location of the target was systematically manipulated to appear with high probability in the same location on the uneven condition trials.

Visual search and spatial regularities

To investigate the facilitation of target discrimination as a function of statistical frequency, we used a visual display containing 6 items, one target (either F or L) and five distractors (T or E). There were 18 possible locations, formed by a grid of 6 vertical columns by 3 horizontal rows (see Figure 1), although this grid was not visible to the participant. Six letters appeared on each trial, one in each column. Participants responded by pressing one button for “L” targets and another for “F” targets. The probability manipulation was implemented across two conditions that appeared sequentially in separate blocks of trials. In the *baseline* condition, targets were equally likely to appear in any of the six columns. In the *uneven* condition, targets appeared on one half of the screen (e.g., columns 1-3) with 80% probability and on the other half (e.g., columns 4-6) with 20% probability. The target was equally likely to appear in all possible locations within the selected screen side. The screen side containing 80% of the targets was counterbalanced (left or right). No mention of the probability manipulation was made at the beginning of the experiment; participants were simply instructed to indicate which target was present as quickly and accurately as possible.

To ensure that subjects maintained central fixation, prior to the onset of the visual search display they reported a digit from 1-9 that appeared centered over fixation. To gauge their awareness of the probability manipulation, at the end of the experiment participants were asked, "Did you feel that the target was more likely to appear in one location or region, or did you feel that targets were well distributed?" and the response was recorded.

We tested two groups of normal subjects, a young group consisting of college students, to ascertain the extent of the probability effect, and then a group of elderly subjects (to serve as controls for the patients with hemispatial neglect, see below). All participants were right handed and had normal or corrected-to–normal vision. Subjects made very few errors (1% and 2.5% for the young and elderly subjects) and so the analyses were performed on reaction time (RT). Because the side of space on which the probability was manipulated did not influence performance, the location factor was collapsed for the analysis. Also, because both young and elderly subjects were influenced by the probability manipulation to an equivalent extent, the age factor was collapsed for the analysis. The critical finding was that significant differences between the probability conditions were observed in all columns except *5*, which showed the same numerical trend (see Figure 2). However, because the two probability conditions were always run in sequence, with the baseline first so as to prevent contamination from the altered probability distribution, it was difficult to determine whether decreases in RT were due to general practice effects and/or to the probability manipulation. A comparison of the RT difference between columns *within* each probability condition provided further answers. Pairwise comparisons revealed the following: In the *baseline* condition, none of the column pairs differed significantly from each other. In the *uneven* condition, however, columns *1* and *2* were significantly different from columns *6* and *5*, respectively. This comparison confirmed that targets in the left-most columns were detected more quickly than targets in the right-most columns but only when the statistics governing target location were biased towards the left side of the screen.

Twelve of the sixteen undergraduate participants and all of the elderly participants reported having no awareness of the probability distribution at the end of the experiment; re-running the analysis excluding the four who reported some awareness did not alter the findings. That participants report no obvious tracking of the probability suggests that the results are not due to explicit anticipation of target location at the beginning of each trial but

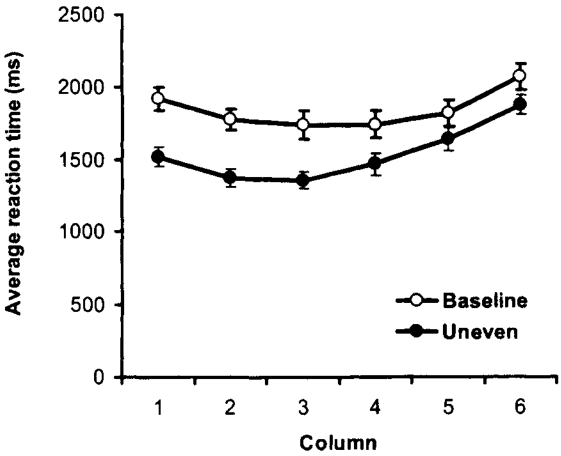

Fig. 2. Mean reaction time as a function of screen column for control participants for baseline and uneven conditions. Note that the data from the young and elderly control participants are collapsed here. Error bars indicate standard error.

rather that the spatial contingencies are being coded implicitly. From these data, we conclude that young and elderly normal participants are sensitive to the probability distribution of target objects, even when the distribution is over a region that includes several locations and when there is no explicit awareness of the contingency. We take these results to be a clear demonstration of how a flexible and adaptive orienting system may direct attention optimally in response to statistical contingencies in the visual field in normal individuals.

To explore further the consequences of the probabilistic distribution of targets on spatial representation, we conducted the same experiment in individuals with hemispatial neglect. Hemispatial neglect (or neglect, for short) is a deficit in representing contralesional space, acquired following a brain lesion. Individuals with this disorder fail to notice or report information on the side of space opposite the lesion, despite intact sensory and motor processes (Bartolomeo & Chokron, 2001; Bisiach & Vallar, 2000). Thus, for example, patients with a right hemisphere lesion fail to copy features on the left of a display despite incorporating the corresponding features on the ipsilesional right. The same individual may eat from only the right side of their plate or dress only the right side of their body. The deficit may affect all sensory modalities, including contralateral visual, auditory, somatosensory, and olfactory inputs. The presence of neglect may also adversely affect manual and oculomotor behavior in that these patients often are impaired at directing their eyes and/or hand to the contralateral side, even in the absence of visual input (Gore, Rodriguez, & Baylis, 2001/2002; Hornak, 1992; Mattingley, Husain, Rorden, Kennard, & Driver, 1998). Finally, neglect can even affect the contralateral side of an internal representation in the absence of sensory input, and can be reflected in mental imagery, as so elegantly demonstrated in the seminal work by Bisiach and Luzzatti (1978).

Many studies have demonstrated a significant impairment in the visual search abilities of neglect patients (Aglioti, Smania, Barbieri, & Corbetta, 1997; Behrmann, Ebert, & Black, 2004; Eglin, Robertson, & Knight, 1989; Esterman, McGlinchey-Berroth, & Milberg, 2000; Riddoch & Humphreys, 1987). There is evidence, however, that patients with neglect are able to exploit explicit spatial cues such as arrows indicating the target location, or verbal instructions to orient leftwards (Halligan, Manning, & Marshall, 1991; Lin, Cermak, Kinsbourne, & Trombly, 1996; Riddoch & Humphreys, 1983). The critical question is whether these individuals with neglect are able to exploit spatial contingencies in the same way as normal participants. To assess this, we examined the impact of statistical regularities of target location as an orienting cue in relation to the spatial gradient of neglect behavior with seven individuals, all of whom had sustained a lesion to the right hemisphere and all of whom exhibited left-sided visual neglect on the Behavioral Inattention test (Wilson, Cockburn, & Halligan, 1987).

As is evident in Figure 3a, the critical finding was the presence of a significant interaction between condition (baseline, uneven) and column of target. Pairwise comparisons of corresponding columns in the two probability conditions revealed a significant reduction in RT in columns *1-3* in the *uneven* compared with the *baseline* condition but no significant change in columns *4-6*. Results from the *baseline* condition were consistent with classic symptoms associated with hemispatial neglect: columns *1* and *2* were significantly slower than columns *6* and *5*, whereas column *3* was not significantly different from column *4*. In the *uneven* probability condition, however, discrimination performance in column *1* was still significantly slower than column *6*. Importantly, there were no significant differences between columns *2* and *5* and columns *3* and *4*.

To assess whether the effect of statistical cueing was qualitatively different for control vs for patient populations, difference ratios between the two conditions were calculated for patient and for control participants for each column (see Figure 3b). Note that the control subjects here are just the elderly subjects described above. Most notably, the population (control, patient) x column difference ratio interaction was not significant, indicating that the change in performance between the *baseline* and *uneven* condi-

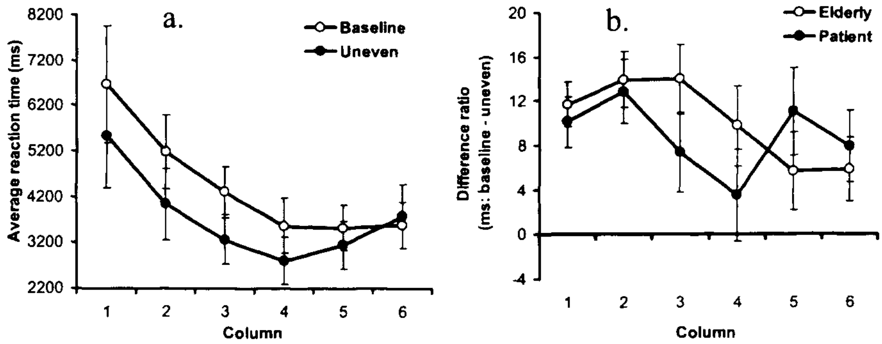

Fig. 3. Mean reaction time as a function of screen column (a, left panel) in patients with hemispatial neglect for baseline and uneven conditions and mean difference ratios as a function of screen column for elderly controls and neglect patients (b, right panel). Error bars indicate standard errors.

tions as a consequence of the contingency in target location was equivalent in elderly and patient participants. As with the normal participants, none of the patients reported having noticed the probability difference during the experiment, further suggesting that the results are not a consequence of explicit strategy formation.

In sum, our data demonstrate that neglect patients show an additive sensitivity to statistical contingencies governing the distribution of targets in the visual field, that their behavior is modulated without explicit knowledge, and that the relative decrease in RT between conditions is equivalent to that seen in elderly participants. The results indicate that the behaviors of both normal and patient populations reflect sensitivity to the statistical spatial contingencies. Importantly, despite the obvious ability to exploit these contingencies, participants report being unaware of the uneven distribution of target locations. These results provide an important demonstration of how the visual attention system may adapt to environmental statistics reflexively in order to maximize the efficiency of behavioral output.

What neural mechanism might track these statistical effects? At least three possibilities exist: the facilitation occurs during the perceptual encoding of the input, during the sensorimotor transformation between the visual input and motor response (Platt & Glimcher, 1999), or during the planning or execution of the response. Although we do not definitively know the answer, the results from the patients render the second possibility unlikely because the effect of the uneven cueing did not alter the attentional gradient of patients per se. Furthermore, because neglect is often thought of as resulting from damage to regions of the brain that implement sensorimotor transformations (Andersen, Snyder, Bradley, & Xing, 1997; Behrmann, Ghiselli-Crippa, Sweeney, Dimatteo, & Kass, 2002), it is likely that the facilitation reported in patients occurs in the encoding or the response process. The notion that the uptake of the target information is facilitated by the contingencies is consistent with the finding that early ERP components such as lateral occipital P1 and N1 are larger for targets appearing in expected rather than unexpected locations (Handy, Green, Klein, & Mangun, 2001). It is also in agreement with fMRI evidence that top-down attentional effects can selectively enhance V1 activation with concomitant suppression in surrounding regions; selective enhancement may act to reduce competition when multiple stimuli are present (Fink, Driver, Rorden, Baldeweg, & Dolan, 2000; Sengpiel & Huebener, 1999).

These results suggest that attentional expectancies in this experiment (although implicit) may provide feedback to early visual areas to enhance processing of objects located in the most probable region. It is also possible, however, that the contingencies facilitate subject responses, in this case, the saccadic eye movements that are necessary for target discrimination. The facilitation in target discrimination may arise because neurons involved in coding saccadic eye movements to the more probable side of space are primed. For example, Basso and Wurtz (1998) recorded from buildup neurons in the superior colliculus of monkeys performing a saccadic eye-movement task. They found greater activation during the delay period prior to target selection when the target always appeared in the same location compared to when it appeared in different locations. Their findings suggest that presaccadic activation is modulated by increased target location probability.

At present, exactly what gives rise to this facilitated discrimination performance as a function of contingency remains to be determined. Some functional imaging studies on this topic are under way and promise to be illuminating. We now turn to examining statistical learning of shapes, where we are better able to suggest a neural mechanism that likely supports this form of learning.

Learning and acquisition of shape regularities

Statistical learning has been demonstrated for frequently co-occurring shapes embedded in simple displays (Chun & Jiang, 1999; Edelman et al., 2002; Fiser & Aslin, 2001). In these studies, observers typically are presented with a series of visual displays containing multiple stimuli. For example, Fiser and Aslin (2001) used displays comprising a three-by-three grid containing six simple shapes. Across such displays, the joint probability (probability of co-occurrence) or conditional probability (probability of stimulus A given the presence of stimulus B) of stimulus pairs varies systematically. Learning of these stimulus statistics has been shown with a number of different dependent measures. Edelman, Hiles, Yang, and Intrator (2002) measured statistical learning as the greater reduction in reaction time for frequent compared with infrequent stimulus pairs in a probe detection task. Fiser and Aslin (2001) found that, in a forced-choice familiarity judgment task, observers could discriminate between frequent and infrequent stimulus pairs, suggesting an explicit representation of stimulus statistics. However, Chun and Jiang (1999) have argued that the memory may be implicit. They found shorter reaction times for frequent over infrequent target-distractor pairings in a visual search task, in the apparent absence of explicit memory for the target-distractor associations, measured in forced-choice familiarity judgments.

Although there are now several elegant studies in the domain, a number of questions persist – What factors influence performance? Do bottom-up factors such as perceptual organization override statistical regularity? Is it necessary to attend to the entire display to obtain the statistical effects? Is the sensitivity to the statistics explicitly reportable by participants? What neural mechanism mediates the learning? To examine this form of learning in more detail, we (Chris Baker, Carl Olson, and Marlene Behrman) developed a paradigm that could be used with both humans and monkeys; we report these findings here. In the humans, we measured RT and we also tracked performance in a forced-choice familiarity judgment to provide a comparison with the studies above (Baker, Olson, & Behrmann, 2004).

Acquiring new visual shape representations in normal participants

In the experiments, displays were composed of two simple geometric stimuli (Figure 4) either unconnected or connected by a vertical bar. The total height of the displays was approximately 2.5 degrees of visual angle and the distance between the two stimuli was approximately 1 degree. There were eight target stimuli and eight distractor stimuli. Displays were constructed by combining one target and one distractor, producing 32 different displays. Each target was associated with a given response (left or right). Each distractor was paired equally often with left and right targets, so distractors carried no information about the appropriate response.

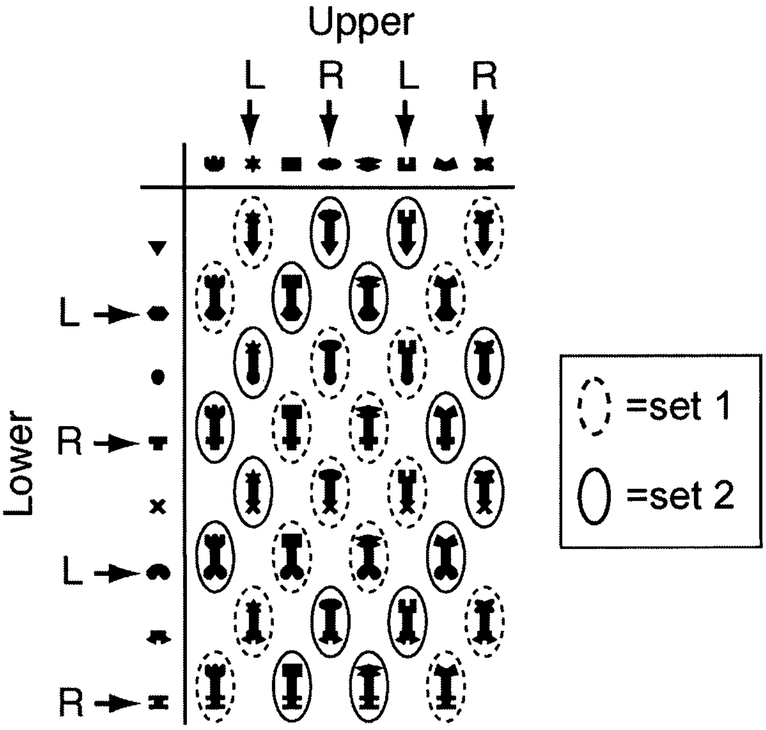

Fig. 4. Stimulus set for exploring visual pattern learning. The eight target parts are indicated by arrows and annotated with the designated response (R = right, L = left). The remaining eight parts are distractors and were equally associated with left and right responses. The solid (set 1) and dotted (set 2) ovals surrounding each stimulus indicate the frequency set to which the stimulus was assigned.

The critical manipulation employed in the experiments was the frequency of presentation of specific target-distractor combinations. Frequent combinations were presented four times as often as infrequent combinations. It was reasoned that if participants processed the target-distractor combinations they would respond faster and more accurately to the frequent than to the infrequent combinations. Displays were divided into two equal sets (set 1 and set 2, Figure 4). For a given participant, one set was designated "frequent" and the other set "infrequent," with set counterbalanced across participants. Each target was paired frequently with two distractors and infrequently with another two.

At the start of each trial, a fixation point was presented at the center of the screen and participants depressed two levers, one with each hand. The fixation point turned red and remained so for 500 ms, until it was extinguished and a stimulus was presented for 100 ms. The participants had to release either the left or the right lever depending on the target present in the stimulus. On each trial, feedback was given: three short tones for a correct response and a large red circle flashing on the screen for an incorrect response. These parameters were chosen to be maximally similar to the monkey experiment to be reported next.

At the start of the experiment, participants were informed as to the nature of the task, but were not informed which targets instructed a left response and which a right response. They were allowed to perform practice trials on a separate set of stimuli before engaging in the main experiment. Subjects completed 10 blocks of trials; within every block, the frequent target-distractor combinations were presented four times each and the infrequent combinations once only. At the end of the experiment, participants were presented with 40 different stimuli and asked to rate them on a scale of 1-5 for familiarity (1 = least familiar, 5 = most familiar). All 32 of the experimental stimuli were presented, as well as 8 novel stimuli that had not been presented during the experiment. The novel stimuli were either target-target or distractor-distractor combinations.

In the first experiment, the upper and lower stimuli in the displays were connected. Four targets were presented at the upper location and four targets at the lower location (Figure 4). Participants were not informed which parts were targets and which distractors. Over the course of the 10 blocks, participants showed decreasing RTs and increasing accuracy for both frequent and infrequent target-distractor pairs. Critically, participants were faster and more accurate for frequent target-distractor pairings than for infrequent pairings (Figure 5a and b). Most relevant is the finding of a main effect of frequency on RT and on accuracy (although the latter was only marginally significant in this case). These results indicate statistical learning of the target-distractor combinations. Participants also rated frequent stimuli as significantly more familiar than infrequent stimuli (Figure 5c). This result confirms, in a test of explicit recall, statistical learning of the target-distractor combinations and suggests that the representations are explicit.

We conducted several other experiments to examine further the factors that influence this statistical learning. In one study, we examined whether participants would show the same sensitivity to the statistics if the parts were not connected (Figure 6). Both RT and accuracy showed the facilitation in performance for frequently occurring target-distractor combinations even if the top and bottom were separated, and this facilitation was as great as when they were connected. Participants also rated frequent stimuli as more familiar than infrequent stimuli (and to an equivalent degree whether

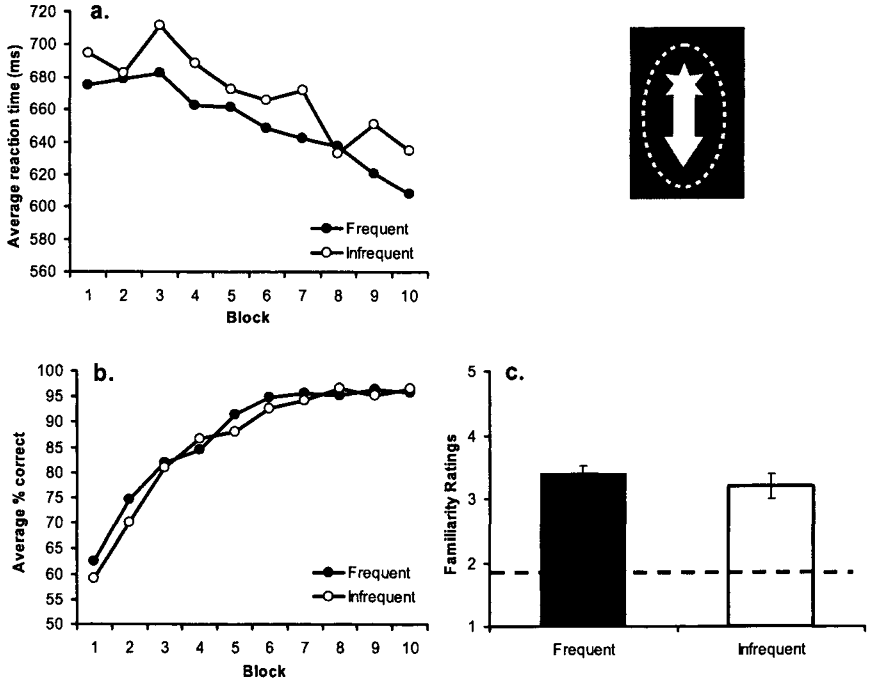

Fig. 5. Mean reaction times (a, top left panel); mean accuracy (b, bottom left panel); and mean familiarity ratings (c, bottom right panel) for subjects showing better performance on all measures for frequent target-distractor pairs over infrequent when subjects attend to targets at the bottom or top positions and when the parts are connected.

connected or not). That performance across the different dependent measures is equivalent independent of whether the parts are connected or not is surprising but suggests that learning is so robust that perceptual organization principles such as uniform connectedness (Palmer & Rock, 1994; Saiki & Hummel, 1998) are not necessary to bind the component parts together.

In the two experiments just described, targets were presented at both the upper and lower locations (unpredictably) so that participants had to attend to both locations. This attention might have served to bind the frequency pairings together. In further experiments, we asked whether the effect observed above was dependent on participants attending to both locations. We repeated the same two experiments with the upper and lower stimuli connected in one experiment (Figure 7) but not in a second (Figure 8), but in both cases, all eight targets were presented at one location only (either

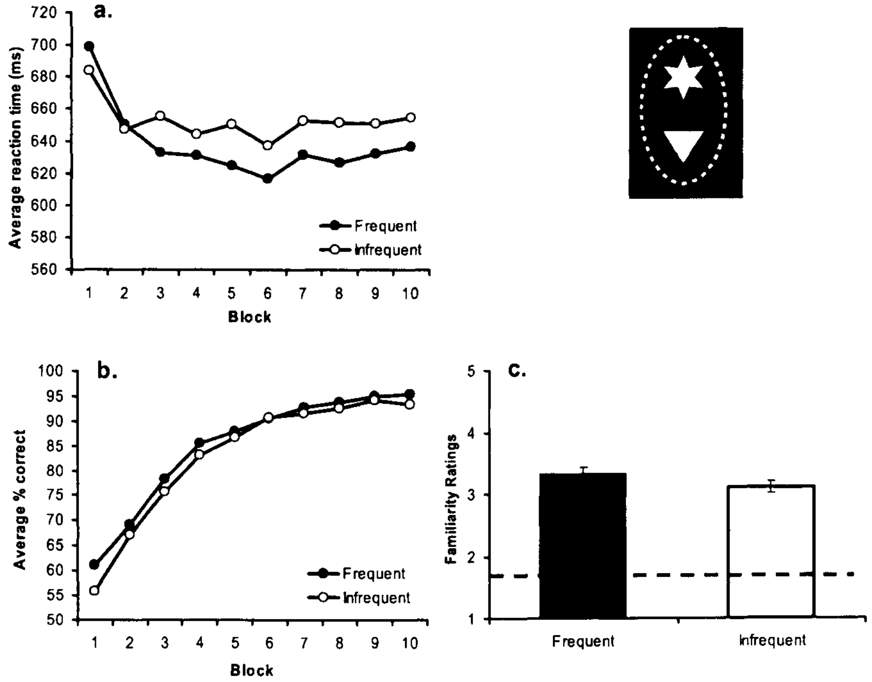

Fig. 6. Mean reaction times (a, top left panel); mean accuracy (bottom left panel); and mean familiarity ratings (c, bottom right panel) for subjects showing better performance on all measures for frequent target-distractor pairs over infrequent when subjects attend to targets at the bottom or top positions but when the parts are not connected.

upper or lower, between subjects). Interestingly, even when participants are required to attend to one location only, they still show statistical learning of the target-distractor combinations regardless of whether they are attending to the upper location only or the lower location only when the stimuli are connected. This facilitation by frequency was also apparent in the subjects' explicit recall on the familiarity-rating task. However, when participants had to attend to one location only and the parts were unconnected, they no longer showed statistical learning of the target-distractor combinations. Under these conditions, participants were not faster nor were they more accurate for the frequent target-distractor combinations than for the infrequent combinations, and participants gave similar familiarity ratings to the frequent and infrequent stimuli. These results indicate that when participants have to attend to one location only and the parts are

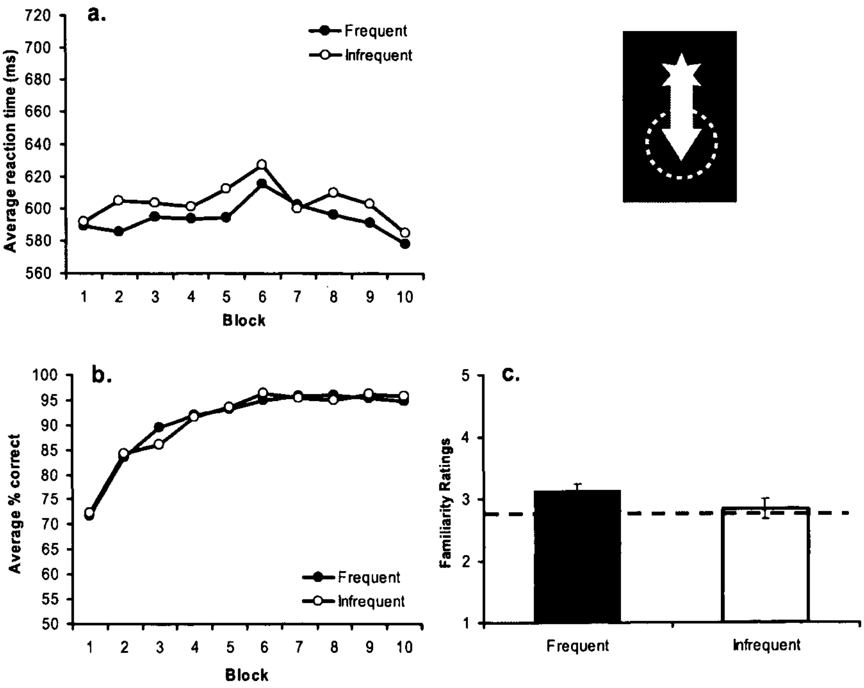

Fig. 7. Mean reaction times (a, top left panel); mean accuracy (bottom left panel); and mean familiarity ratings (c, bottom right panel) for subjects showing better performance for frequent target-distractor pairs over infrequent when subjects attend to targets at the bottom position and when the parts are connected.

unconnected, they no longer show statistical learning of the target-distractor combinations.

Taken together, these findings suggest that both attention and perceptual grouping can modulate visual statistical learning and that, importantly, these two factors interact. When participants attended to both stimulus locations, statistical learning was observed regardless of whether the stimuli were connected or not. When the participants attended to one location only only, however, statistical learning was observed only when the stimuli were connected. Attention to the individual stimuli appears to be necessary, although this could be produced voluntarily by explicit direction of attention or involuntarily by the automatic spreading of attention induced by perceptual grouping. This suggests that in real world scenes, in the absence of explicit attentional control, statistical learning of feature combinations is much more likely for connected features than for unconnected features.

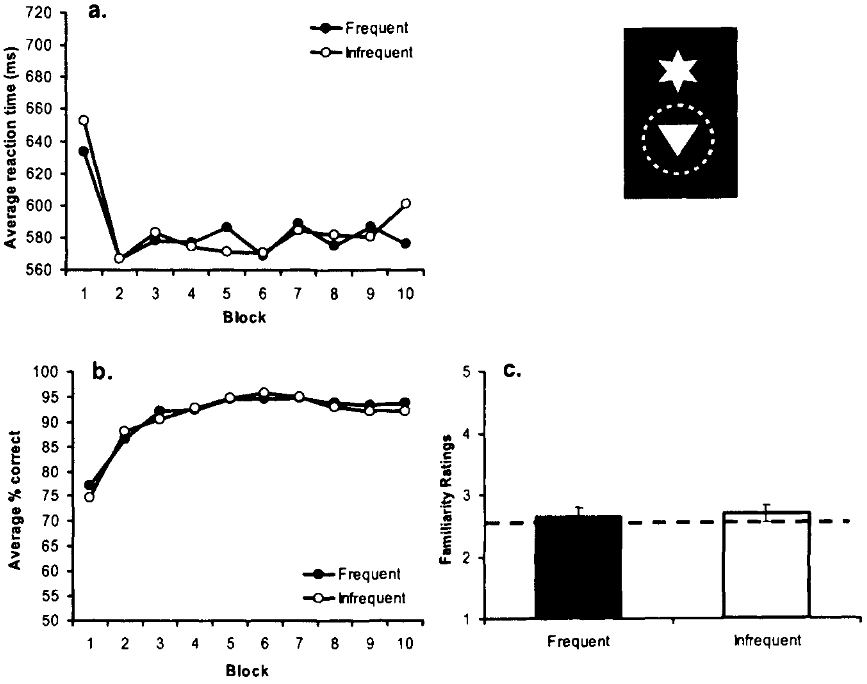

Fig. 8. Mean reaction times (a, top left panel); mean accuracy (b, bottom left panel); and mean familiarity ratings (c, bottom right panel) for subjects showing no difference in performance for frequent target-distractor pairs over infrequent when subjects attend to targets at the bottom position and the parts are not connected

The statistical learning just described suggests that participants may be automatically encoding the upper and lower stimuli as a single whole object and forming unitary representations of the stimulus displays when attending to its entirety. Recent neurophysiological data from monkeys provide a possible neural mechanism by which such unitization could occur, as seen in the next section in which we describe an experiment in which we trained monkeys on a discrimination task using the same stimuli and found an increase in the number of neurons in inferotemporal cortex coding the conjunction of visual features.

Acquiring new visual shape representations in non-human primates

The results just reported indicate that humans are sensitive to repeated combinations of top and bottom parts of an object even if one part is not relevant for the response, revealing considerable statistical learning. The question that arises is what neural system might possibly mediate this pattern of acquisition. One obvious candidate is inferotemporal (IT) cortex, given that neurons in this region have been shown to respond more similarly to visual stimuli that have been paired in prior training than to non-paired stimuli (Messinger, Squire, Zola, & Albright, 2001; Sakai & Miyashita, 1991). These results are also consistent with the data showing that lesions to IT impair pattern recognition. To examine the role of IT in pattern acquisition, we (Chris Baker, Carl Olson, and Marlene Behrmann) trained two monkeys in a discrimination task using the same stimuli that we had used for humans (bottom and top connected) (Baker et al., 2002). We then recorded from single neurons during a fixation task while the monkey fixated both learned and unlearned stimuli.

In this experiment, to ensure that there were no new emergent features when the top and bottom were juxtaposed (and that this single emergent feature was what the monkey learned, rather than the co-occurrence of the top and bottom part), we assembled tetrads of the stimuli by combining two top parts and two bottom parts orthogonally in a 2 x 2 design (see Figure 9). In the discrimination task, the monkey was taught to respond with a lever (right or left) depending on a particular combination of a top and bottom part. Because no part definitively indicated the response, to associate the stimuli with a response side, the monkey had to encode both the top and bottom part (see Figure 9). Each monkey was trained on two tetrads with the remaining two serving as the unlearned controls; learned tetrads for one monkey served as the unlearned controls for the second monkey and vice versa (see Figure 9 for examples). Once the monkeys performed the task well, we directly compared the neural responses elicited by learned versus unlearned stimuli. Recording sites, localized by magnetic resonance imaging, occupied the ventral aspect of the temporal lobe lateral to the anterior medial temporal sulcus, and thus were all in visual area TE of the inferior temporal lobe (see Figure 10 for recording site for monkey 1).

In the fixation condition, we assessed the neural response to all 16 stimuli and then chose one learned and one unlearned tetrad that evoked a neural response. Across the two monkeys, this was done 502 times (monkey 1: 331, monkey 2: 171). We were particularly interested in the number of

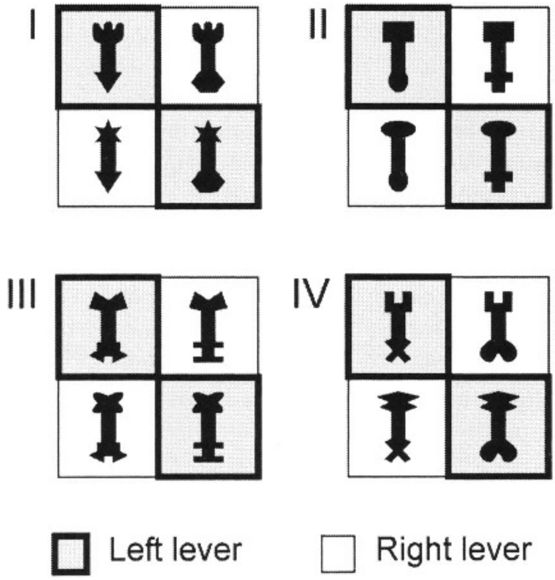

Fig. 9. Four tetrads of batons were used in discrimination training. Monkey 1 was trained on tetrads I and II and monkey 2 on tetrads III and IV. The batons that were used for training one monkey were also used as unlearned controls for the other monkey. Batons requiring left and right-lever responses are indicated by the different boxes around the stimuli. During the experiment, the boxes were not present.

neurons that responded selectively to a specific combination of a top and bottom part (see Figure 11 for an example), and to the extent that this selectivity differed for learned versus unlearned stimuli. To quantify the differential selectivity for the learned versus unlearned stimuli, for each neuron, we performed a two-way ANOVA with top and bottom part as factors, separately for learned and unlearned stimuli, and then counted up how many neurons showed no sensitivity to either the top or bottom part, one main effect, two main effects, or the interaction.

The schematic depiction of these various outcomes is shown in Figure 12, with the size of the circle showing the strength of the response. As is evident from Figure 13, in which we simply plot the number of neurons exhibiting a particular outcome on the ANOVA, there were no differences for the number of neurons that showed either one or two main effects for learned versus unlearned displays. There were, however, more frequent interactions of top and bottom factors for learned versus unlearned stimuli and fewer neurons showing no sensitivity for learned over unlearned stimuli.

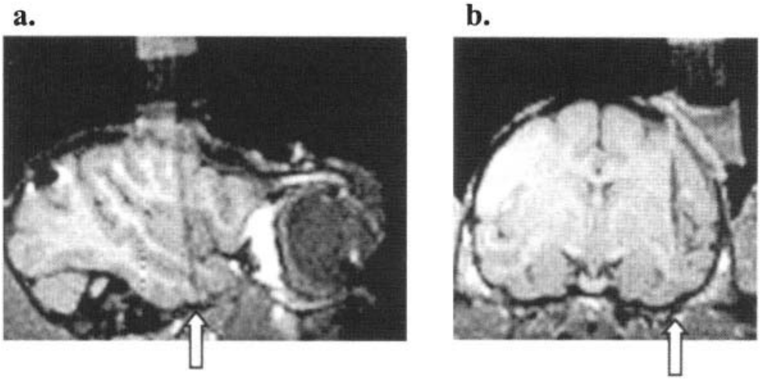

Fig. 10. Magnetic resonance images showing the recording site in the ventromedial cortex in monkey 1: (a) sagittal and (b) coronal. The dark line running through the cortex is a shadow surrounding an electrode that was placed at the most medial recording site.

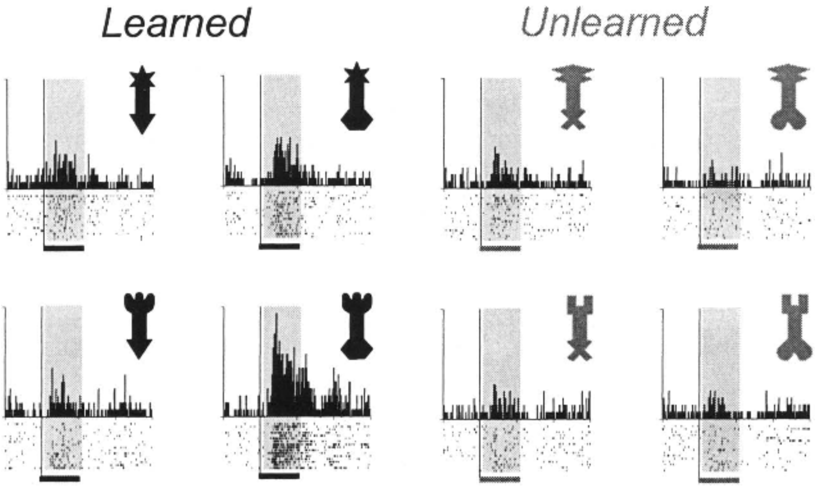

Fig. 11. Spike frequency histograms from a single neuron from Monkey 1 showing greater selectivity of response for combinations of particular top and bottom parts for learned over unlearned stimuli. Traces are aligned on the onset of the 500ms stimulus (vertical line). The duration represented by the entire horizontal axis is 2s.

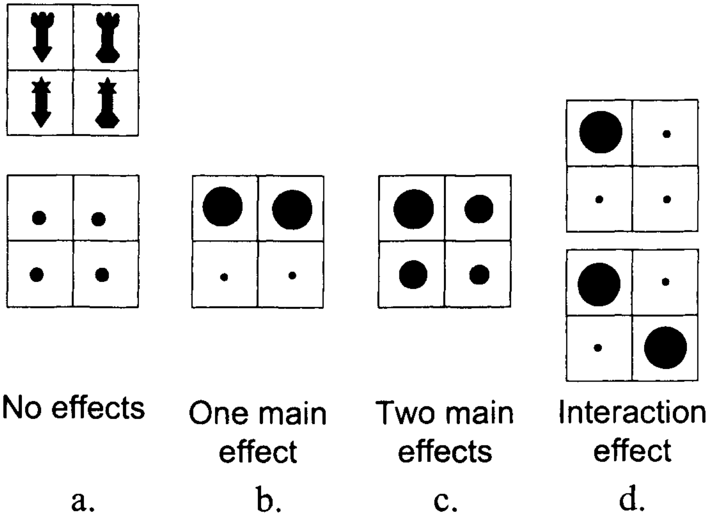

Fig. 12. The two-way ANOVA with top and bottom part as factors could yield a number of possible outcomes, including selectivity (a) for neither part of the object, (b) for one part of the object, (c) for both parts of the object, independently, or (d) an interaction between top and bottom, such that one object produces a strong discharge (upper square) or objects sharing the same behavioral response but no parts in common produce a strong discharge. The interaction of interest here is the former, indicating a preferential response for a combination of a top and bottom part, especially in the learned case.

The important finding is that stimuli evoked a differential response from the neuron if the particular combination was learned. We note, however, that the statistical interaction of top and bottom factors need not necessarily emerge from the selective response in which we are interested (see Figure 12). For example, an interaction might also be observed if the two stimuli on the diagonal both elicited strong neural responses. Such a result emerges from an association of the stimuli with a particular response (recall that left and right responses are aligned with the stimuli on the diagonal) and is not of interest for this current investigation.

The final analysis consisted of ensuring that the increased number of neurons showing the top x bottom interaction indeed displayed the superadditivity or nonlinearity of the component parts for one of the four stimuli. This was indeed the case, suggesting that, over the course of experience, the neurons came to represent not only the parts, as evident in the persisting main effect of parts, but also the combination of parts. A mechanism such as this might underlie the increased sensitivity to frequency observed in human experiments reported above, and demonstrates the ability

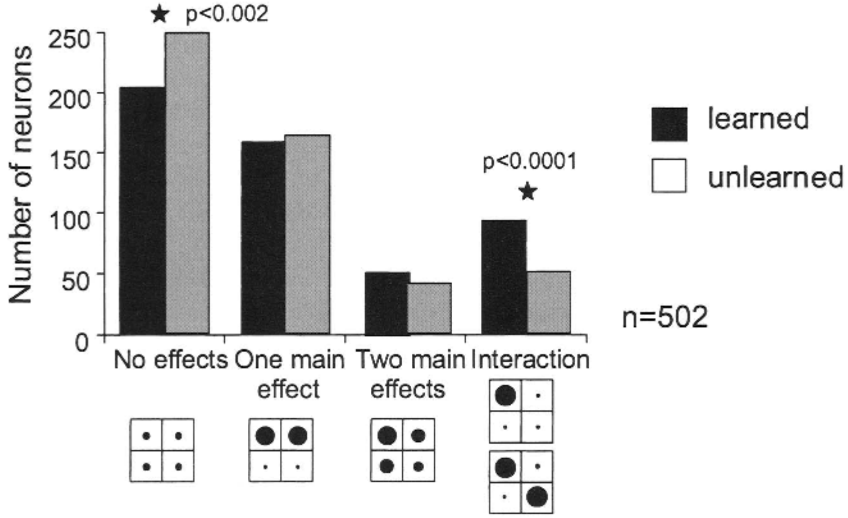

Fig. 13. The particular outcomes of the ANOVA from Figure 12 conducted separately for each neuron. The responses for each neuron appear in only one bar for learned and one for unlearned. The totals for the learned bars and the unlearned bars are 502 each. If a neuron showed a main effect and an interaction effect, then in this plot, it went into the interaction bar only. The major difference is the smaller number of neurons which showed no sensitivity for either part for the unlearned batons, and the greater number of neurons which showed the top x bottom interaction for the learned compared with the unlearned batons.

of inferotemporal (IT) cortex to acquire new visual representations as a function of experience.

Conclusion

The focus of this chapter has been on the processes by which new visual representations are acquired. In particular, this was assessed in a variety of ways by examining the sensitivity of the visual system to the statistics of the input. Studies are described exploring the acquisition of spatial representations by virtue of sensitivity to spatial regularities in the environment. We showed that normal individuals and brain-damaged patients with hemispatial neglect are able to track the regularities, and that this facilitates target discrimination in a visual search task. We also showed that normal individuals are able to learn specific combinations of top and bottom parts of a stimulus and that this learning is so robust that it can survive a disconnection between the parts or attention to only one component. Monkeys trained with the same componential stimuli show neuronal responses that reflect the sensitivity to the particular combinations. Taken together, these findings illustrate how spatial and pattern representations are acquired (and maintained), and demonstrate that the visual system is exquisitely sensitive to the regularities of the input.

Author Notes

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Top-Down and Bottom-Up Processes in the Perception of Reversible Figures: Toward a Hybrid Model

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Summary. Reversible figures such as the Necker cube are ambiguous visual patterns that support at least two markedly different perceptual organizations. During a period of continuous viewing, observers' conscious experience fluctuates, alternating between the possible interpretations. Attempts to explain this multistable perceptual character of reversible figures traditionally have attributed reversals to *either* bottom-up (stimulus driven) *or* top-down (conceptually-driven) processes. In the former case, perceptual fluctuations are attributed to the alternating fatigue and recovery of competing cortical organizations. In the latter case, perception is thought to be analogous to a hypothesis-testing or problem-solving process that successively considers alternative "solutions" to the perceptual puzzle represented by a reversible figure. We argue for a hybrid theoretical framework in which both types of processes contribute to figure reversals. By explicitly recognizing the contributions of both lower-level sensory processes and higher-level cognitive processes, the hybrid approach can resolve apparent conflicts in the reversible figure literature by calling attention to the fact that different viewing conditions can differentially engage top-down and bottom-up processes. The approach also provides a framework for future research, encouraging work that addresses how bottom-up and top-down processes are coordinated and how their effects are integrated in determining conscious perceptual experience.

Key words. Perceptual organization, reversible figures, ambiguous figures, multistable perception, top down processes, bottom up processes

Introduction

Reversible figures are ambiguous visual patterns that support at least two markedly different perceptual interpretations. One famous example is the

Necker cube which is shown in Figure 1a and which can be seen as having its front surface oriented either downward or upward. Other well-known examples include the vase/faces figure and the young woman/old woman, which are shown in Figures 1b and 1c, respectively.

These ambiguous patterns are not just idle curiosities. Many vision theorists have argued that ambiguity is the hallmark of the retinal stimulus in almost all visual perception and that, to adapt effectively to its environment, the organism must routinely resolve this ambiguity (e.g., Andrews, Schluppeck, Homfray, Matthews, & Blakemore, 2002; Medin, Ross, & Markman, 2001; Rock, 1975). What makes reversible figures special is that the perceptual system seems unable to settle upon a single stable organization. Thus, during a period of continuous viewing, an observer's conscious experience fluctuates, as first one and then another of the possible interpretations is seen. This characteristic of reversible figures in which only one of the possible organizations can be perceived at any point in time is sometimes referred to as the "property of exclusivity" (Leopold & Logothetis, 1999). The fact that perceptual experience fluctuates in the absence of any change in the external stimulus has suggested to many researchers that reversible figures may be particularly useful in revealing the visual and cognitive processes that interpret the inherently ambiguous retinal array and, thereby, lead to conscious visual awareness (Andrews et al., 2002; Kornmeier & Bach, 2004; Leopold & Logothetis, 1999).

Over the years, a variety of theories have been proposed to account for reversible figure effects (see Long & Toppino, 2004, for a review.) Most of these can be classified into one of two groups that differ in the nature of the assumed underlying mechanisms. In one kind of theory, reversibility is explained in terms of higher level cognitive processes that exert a top-down influence on the interpretation of ambiguous retinal stimulation. In the other kind of theory, the proposed explanation is in terms of relatively passive, stimulus driven or bottom-up mechanisms.

Top down theories have emerged from the tradition that conceptualizes perception as requiring problem-solving or decisional processes that are constrained by limited attentional resources and are influenced by experience. Thus, prominent top-down theories attribute reversals to fluctuations of attention (e.g., Kawabata & Mori, 1992), alternating decision processes (e.g., Rock, 1975), or successive testing of perceptual hypotheses (e.g., Gregory, 1974), as the perceptual system attempts to access and fit first one and then another visual representation to the retinal pattern. Consistent with this view is the well documented sensitivity of reversible figures to the influence of such factors as learning, expectation, the viewer's intentions, and rival demands on attentional resources. Finally, the property of

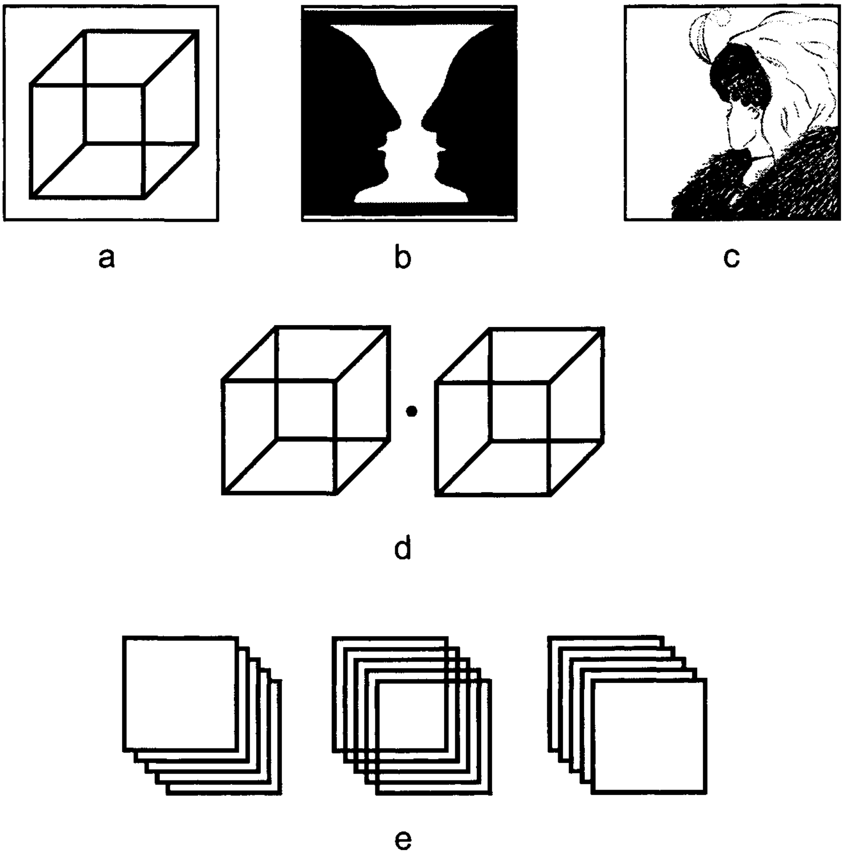

Fig. 1. Reversible figures: (a) Necker cube (Boring, 1942), (b) Vase-faces (Rubin, 1915/1958), (c) Young/old woman (Boring, 1930), (d) Side-by-side copies of a Necker cube, (e) Overlapping squares figure in the center flanked by the two unambiguous versions of the figure.

exclusivity is attributed, at least implicitly, to the limited attentional character of higher-order cognitive processes. Thus, one presumably can attend to, decide upon, or test, only one possible perceptual interpretation at a time.

The competing class of explanations, so-called *bottom-up theories*, have emphasized the role of lower-level, sensory-based processes. Figure reversals are assumed to reflect the fatigue and recovery of cortical structures that underlie the alternate perceptions of a reversible figure. Initially, this view was associated with the since-abandoned physiological mechanisms proposed by Gestalt theory (e.g., Kohler, 1940). In more contemporary versions such as that proposed by Harris (1980), Von Grunau, Wiggins, and Reed (1984), Toppino and Long (1987), and others, figure reversal has been related to the adaptation and recovery of numerous neural channels that often are proposed to underlie the early stages of visual processing. These channels are viewed as specific to particular stimulus characteristics and to specific regions of the retina. As channels underlying one perception of a reversible figure adapt or fatigue with extended viewing, channels associated with the alternative perception become dominant, causing a phenomenal reversal. As the second set of channels adapts and the first set undergoes recovery, the percept will reverse again. In one prominent view proposed by Attneave (1971), the neural structures underlying the alternate perceptual experiences reciprocally inhibit one another in a relatively passive fashion so that only one set of structures can support conscious experience at any given time. An interesting characteristic of this approach, to which we will return below, is that the mutual-exclusivity limitation on what enters consciousness can be viewed as being localized to a particular pattern in a particular retinal/spatial location.

For most of the last 170 years, since L. A. Necker first described what has come to be known as the Necker cube, most researchers and theorists have sought to explain figure reversal exclusively in terms of top-down mechanisms or exclusively in terms of bottom-up mechanisms. The result is a literature that sometimes seems to be full of contradictions because one can find an impressive array of evidence to support either position. It is our hypothesis that the contradictory character of the literature is a result of the fact that *both* top-down and bottom-up processes play a significant role in figure reversal. We contend that which set of processes dominates in a given situation depends on the particular variables that have been manipulated and often on the particular aspect of perceptual performance that is measured. We propose that a hybrid model which explicitly recognizes the contributions of both top-down and bottom-up processes will be necessary to explain the fluctuations in conscious experience associated with reversible figures.

We have been driven to the hybrid position because our own research has yielded evidence for both kinds of mechanisms – sometimes in the very same study. We propose that several variables, particularly stimulus-related manipulations, have their effect on early, retinally localized cortical structures involved with sensory processing. Alternately, other manipulations, particularly those involving cognitive variables, have their effect through later, more globally organized structures beyond the visual cortex that exert a top-down influence on phenomenal reversals.

In this chapter, we review some of our research that has led us to take this hybrid theoretical position. In particular, we consider three related but separate sets of experiments. These involve, respectively, the effects of extended viewing of a reversible figure, the effects of pre-exposure to an *un*ambiguous version of a reversible figure, and the mechanisms and limitations of intentional control over the perception of reversible figures. In our conclusion, we will sketch out a theoretical framework that we believe will be useful in guiding the evolution of an adequate hybrid model.

Extended Viewing of a Reversible Figure

One of the most reliable findings in all of the reversible figure literature is that reversals become more frequent as the stimulus continues to be viewed (Long & Toppino, 2004). This is well illustrated in one of our own experiments in which we presented observers with a rotating Necker cube (Long, Toppino, & Kostenbauder, 1983). Observers simply viewed the figure passively and pressed a response key each time they experienced a reversal, in this case a perceived change in the direction of rotation. The results are presented in Figure 2a in terms of the mean number of reversals experienced in each 30-sec interval of a 4-min viewing period, and indicate that the rate of reversal increases in a negatively accelerated fashion with extended viewing.

Although this phenomenon has been replicated many times, it has been interpreted differently by bottom-up theorists and by top-down theorists. The former group attributes reversals to the alternating fatigue and recovery of competing neural structures (see Dornic, 1967, for a particularly well articulated presentation of this view). The rate of reversal increases over time because, on each cycle, the channels do not fully recover to the level of the previous cycle. Therefore, it takes progressively less time (until some asymptote is reached) for the channels to fatigue to the point that the next reversal takes place. The contrasting top-down explanation of the pattern shown in Figure 2a attributes the increased rate of reversal to learning that takes place during extended viewing (e.g., Ammons, Ulrich, & Ammons, 1959). The negatively accelerated curve is thought to reflect a standard learning curve. This may reflect increasing knowledge of where to shift attention within a figure to favor one percept or the other. Or, with practice, the observer may become progressively more facile at accessing the internal representations of the alternate percepts.

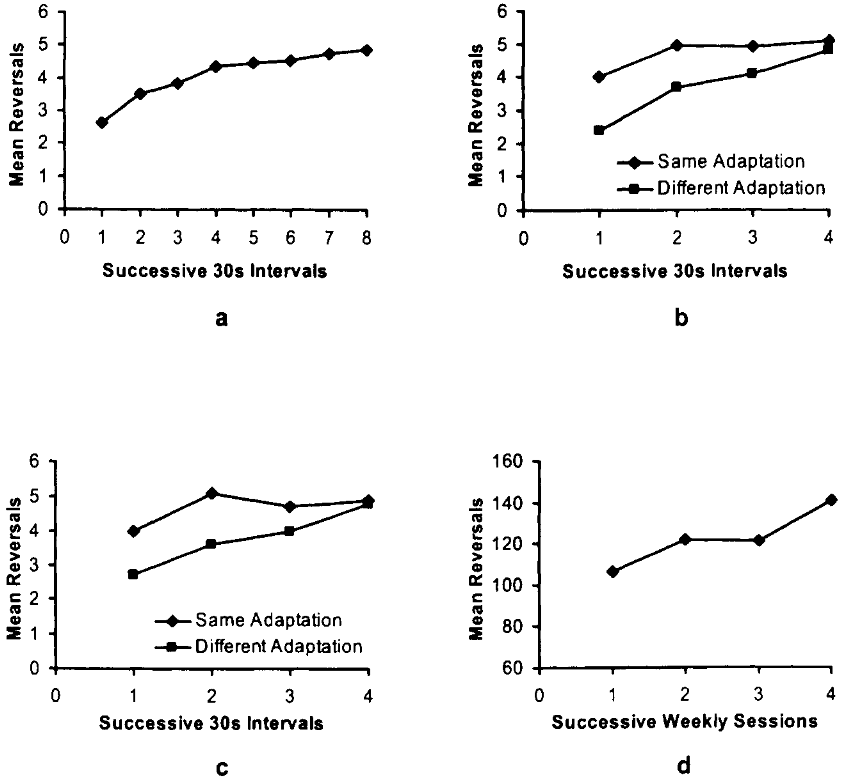

Fig. 2. (a) Change in reversal rate of a rotating Necker cube as a function of viewing time (in four minute viewing period). (b) Reversal rate of a single rotating cube as a function of viewing time (in 2 minute test period) following adaptation to a rotating cube presented to the same or different retinal locations. (c) Reversal rate of two simultaneously presented rotating cubes as a function of viewing time (in 2 minute viewing period) where one is presented to the same retinal location as a previous adaptation cube and the other is presented to the opposite visual field. (d) Mean reversals as a function of successive weekly sessions involving the viewing of rotating Necker cubes.

In an attempt to differentiate between these hypotheses, we asked whether the effects of extended viewing were specific to retinal locations. It is well known that the neural activity of cells in the visual cortex is limited to stimulation within their receptive fields, that is, to specific retinal regions. Consequently, if phenomenal reversals are in any way subject to the fatiguing of those sets of cortical cells that underlie each perceptual experience, then increased reversal rate with extended viewing of a reversible figure should depend critically upon the same retinal location being continually stimulated. A change in retinal location during the viewing period should largely eliminate the effect of prior viewing, and reversal rate should drop to nearly its original level. This simple prediction does not seem to follow easily from the top-down hypothesis because learning is typically conceived of as affecting perception at higher, more global, levels of operation.

We tested these predictions in an experiment in which observers passively viewed a rotating Necker cube and pressed a response key whenever they experienced a reversal (Toppino & Long, 1987, Experiment 1). Each viewing period was 4-min long and was divided into a 2-min adaptation period and a 2-min test period. Observers maintained their gaze on a centrally located fixation point during the entire viewing period. During the adaptation period, they viewed one rotating cube that was presented either to the left or to the right of fixation. During the immediately following test period, observers viewed a rotating cube that was either in the same location as the adaptation stimulus or in a different location on the opposite side of fixation.

The critical results are presented in Figure 2b in terms of the mean number of reversals reported as a function of successive 30-sec intervals during the 2-min test period. The upper curve labeled "same adaptation" represents the conditions in which the test cube was in the same location as the preceding adaptation cube. In this case, the reversal rate was relatively high from the very beginning of the test period. The slope was shallow presumably because the reversal rate had already begun to approach its asymptote by the end of the preceding 2-min adaptation period. In contrast, the lower curve labeled "different adaptation" represents the conditions in which the adaptation and test cubes were presented to different locations. In this case, the reversal rate was relatively low at the beginning of the test period and gradually increased until it approximated the level of the same-adaptation condition. Interestingly, the different adaptation condition did not differ from a no-adaptation condition which is not included in Figure 2b. That is, observers in the different-adaptation condition were behaving as if they had seen no cube during the adaptation phase.

We contend that these results are exactly what one would predict on the basis of the neural-channel hypothesis. Reversal rate was expected to be high from the beginning of the test period when the test cube appeared at the same retinal location as the adaptation stimulus because the same set of neural channels was involved throughout. However, the effect of prior adaptation was expected to be largely nullified when the test cube appeared at a different retinal location from that of the adaptation stimulus because the neural channels involved during the test period differed from those engaged during adaptation.

Additional evidence for the localized character of adaptation was obtained in a second experiment (Toppino & Long, 1987, Experiment 2) in which we varied whether the *size* of a centrally-located rotating Necker cube changed or remained constant from the adaptation period to the test period. When the size of the cube stayed the same, the reversal rate was high during the test period. However, when the size of the cube changed, the reversal rate during the test period was low and did not differ from that of a no-adaptation control.

The involvement of localized neural channels in figure reversal is also suggested by what happens when viewers are presented with side-by-side copies of a single reversible figure such as the pair of Necker cubes shown in Figure 1d. Although there is an initial tendency to see the two copies of the same figure in the same organization, this changes with continued viewing. The two figures soon begin to reverse separately so that sometimes they are perceived to be in the same organization but at other times they are perceived to be in opposite organizations.

In our work, we have questioned whether this simple observation with multiple reversible figures is compatible with the typical explanation of figure reversal based on global top-down learning or on decisional or attentional processes (Long & Toppino, 1981; Long et al., 1983). The prospect of different decisional or attentional processes being applied simultaneously to figures in different parts of the visual field seems unwieldy—although not necessarily impossible. In contrast, a bottom-up model would actually *predict* that fatigue and recovery processes among neural structures corresponding to different portions of the visual field *should* be independent.

As a way of addressing this issue more systematically, we included one final manipulation in the previously described experiment involving the adaptation and test of rotating cubes presented to the same or different retinal locations (Toppino & Long, 1987, Experiment 1). We presented a single rotating Necker cube on either side of fixation during the 2-min adaptation period. Then, during the test period, observers viewed two simultaneously presented cubes—one in the same retinal location as the adaptation stimulus and the other in the opposite visual field. Observers reported perceived reversals in both cubes by pressing two response keys, each of which corresponded to one of the test stimuli. [It should be noted that previous research (e.g., Long et al., 1983) had demonstrated that observers could perform this dual-counting task accurately.]

The results, shown in Figure 2c, nicely replicated the findings obtained when only one cube was presented during the test period (see Figure 2b). The cube in the same location as the adaptation stimulus showed a higher rate of reversal at the beginning of the test period than did the cube presented to a different location. Consider what this indicates about an observer's experience. He or she saw two side-by-side rotating Necker cubes that were reversing at two very different rates. The same-location cube was reversing rapidly whereas the different-location cube was reversing much more slowly. We contend that these data are especially strong evidence for the involvement of localized neural structures in the perception of reversible figures.

All of the above findings that have supported the involvement of a bottom-up mechanism in figure reversal were based on data that were averaged across a number of identical viewing sessions that made up the total experimental session. However, in viewing sessions near the end of the 45-60 min experimental session, observers typically reported significantly more reversals than in earlier periods of the same experiment. Could this be evidence that learning also affects reversal rate? Or, could this just indicate lingering effects of neural fatigue from previous viewing sessions?

To find out, we had some observers participate in four viewing sessions, with a week separating successive sessions (Long et al., 1983). The results, shown in Figure 2d, indicated that the number of reversals in a weekly session increased steadily across the four weeks of the study. Although the results that we described earlier strongly supported the role of a transitory fatigue and recovery mechanism, it is difficult to conceive of such a process exerting effects over a period as long as a week. Instead, these results seem to suggest that learning also contributes to the increase in reversal rate that occurs with extended viewing. Thus, in a series of studies involving very similar stimuli and procedures, the evidence suggests that the perceived alternations of a reversible figure are a function of both stimulus driven processes associated with the fatigue and recovery of localized neural structures *and* higher-order processes in the form of learning.

Effects of Pre-exposure to an *Un*ambiguous Figure

Over the years, a number of studies have exposed observers to an unambiguous version of a reversible figure before presenting the ambiguous version to determine whether prior stimulation altered the likelihood of the observer seeing one or the other interpretation. Curiously, however, two very different sets of results have been reported. Some researchers have found a same-bias effect (e.g., Leeper, 1935). That is, observers tended to perceive the subsequent ambiguous stimulus in the *same* organization as the previously presented unambiguous stimulus. This was taken as powerful evidence for the importance of top-down processes. Prior exposure to the unambiguous stimulus was thought to produce a "set" or expectancy favoring one perceptual alternative. In more contemporary terms, the unambiguous stimulus can be thought of as activating or "priming" one alternative visual representation, thus increasing the likelihood that it will dominate when the ambiguous figure appears.

Other studies, however, have found a reverse-bias effect (e.g., von Grunau et al., 1984). In this case, observers tended to perceive the ambiguous figure to be in the organization opposite to that of the previously presented unambiguous stimulus. This has been taken as powerful evidence for the role of bottom-up processes. Prior exposure to an unambiguous version of a reversible figure is thought to fatigue the neural structures associated with that perceptual alternative so that, when the ambiguous stimulus is presented, the opposite organization dominates.

Initially, it was difficult to know how the apparent contradictions in the literature could be resolved. The studies tended to use different reversible figures and to vary considerably in procedural details. However, we suspected that one variable—the duration of pre-exposure to the unambiguous stimulus—held particular promise as an important moderating variable. Whereas relatively short durations might produce a positive-bias effect by priming a particular visual representation, longer durations might produce a reverse-bias effect by allowing sufficient time for the structures underlying the corresponding perceptual experience to fatigue.

To assess this possibility, we conducted an experiment in which we varied how long observers viewed an unambiguous version of a reversible figure before being presented with the ambiguous version (Long, Toppino, & Mondin, 1992). In one set of observations, we used the ambiguous and unambiguous overlapping squares figures which are illustrated in Figure 1e. In a parallel set of observations, we used the rotating Necker cube. In the case of the Necker cube, the ambiguous figure was the rotating skeleton of a cube, whereas the unambiguous stimuli were solid cubes that clearly rotated in only one direction or the other.

With both kinds of stimuli, the duration of pre-exposure to an unambiguous stimulus was varied from 0 – 150 sec, and observers simply viewed the unambiguous stimulus passively. This was followed immediately by a 30-sec test period, during which observers viewed the corresponding ambiguous stimulus. During the test period, they had two response requirements. First, when the ambiguous stimulus appeared, they reported which configuration they perceived initially. Second, they pressed a response key each time they experienced a reversal throughout the test period.

First, consider the results for observers' initial interpretation of the ambiguous figure when it was presented in the test period. Figure 3a depicts the results for the overlapping squares figure in terms of the mean number of times that observers perceived the ambiguous figure to be in the "same" configuration as the immediately preceding unambiguous stimulus. The solid curve and the dashed curve represent two subsets of observers who were presented a different, but overlapping, range of pre-exposures. Unbiased performance—that is, the level of performance that would be expected if pre-exposure had no effect—is indicated as the level expected by chance. The data reveal that, with short pre-exposure durations, observers exhibited a same-bias effect in that they had an above chance tendency to perceive the ambiguous figure in the same organization as the previous unambiguous stimulus. In contrast, with long pre-exposure durations, observers manifested a reverse-bias effect: They perceived the ambiguous figure to be in the same orientation as the prior unambiguous stimulus less often than would be expected by chance. Exactly the same pattern of results was obtained with the rotating cube figures.

Within a single experiment, we obtained both of the effects that were reported previously in the literature. We showed that whether one observes a same-bias effect or a different-bias effect depends, at least in part, on the duration of pre-exposure. The effect of brief pre-exposure to an unambiguous stimulus seems to reflect a top-down process in which the system is primed to perceive the subsequent ambiguous figure in the same configuration. However, presenting the unambiguous stimulus also apparently initiates a bottom-up process involving neural adaptation or fatigue. As pre-exposure duration lengthens, the adaptation becomes stronger, at first offsetting, and eventually overwhelming, the initial priming effect.

If this analysis is correct, we should also find that the number of reversals experienced during the test period declines with increasing pre- exposure to an unambiguous stimulus. This is because increasing the duration of pre-exposure should produce greater fatigue and suppression of one set of underlying neural structures. As a consequence, it will take longer for those structures to recover enough so that they can compete for dominance. And, until they do, reversal rate will be depressed.

The number of reversals experienced during the test period is shown in Figure 3b for the overlapping squares figure, and the rotating cube stimulus revealed the same pattern of findings. In both cases, the expected results were obtained: The number of reversals experienced during the 30-sec test period declined with increasing pre-exposure duration.

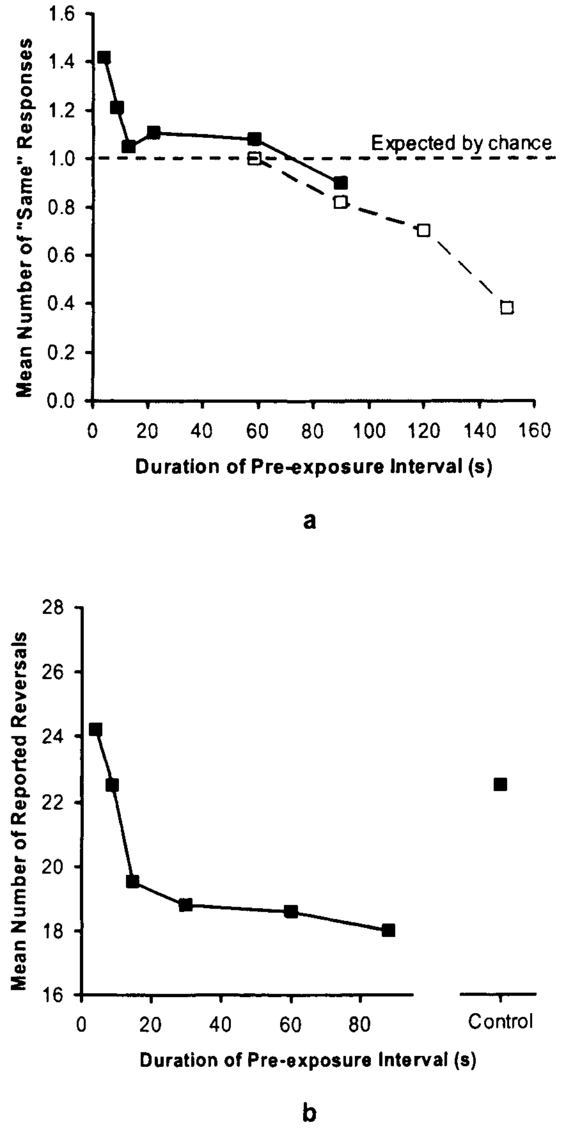

Fig. 3. (a) Mean number of times observers initially perceived the overlapping-squares figure to be in the same orientation as a previously presented unambiguous version of the figure as a function of the duration of pre-exposure. (b) Mean number of reversals experienced with the overlapping squares figure during a 30-sec test period as a function of the duration of exposure to a preceding unambiguous version of the figure.

Although the number-of-reversals data provided converging evidence for the involvement of a neural fatigue mechanism, one should not lose sight of the more general conclusion based on the observers' initial perceptions. In a single experiment, we obtained evidence for the operation of both top-down and bottom-up processes. The type of process that was most apparent in the data depended upon the viewing conditions, with the duration of pre-exposure to the unambiguous stimulus playing the critical moderating role in this particular case.

Intentional Control: Mechanisms and Limitations

In discussing our previous experiment, we proposed a priming explanation of why a relatively brief pre-exposure to an unambiguous stimulus produced a same-bias effect when observers subsequently viewed the ambiguous figure. The idea was that exposure to the unambiguous version of the stimulus activated a particular underlying visual representation and that the activated representation was likely to dominate in the initial perception of the ensuing ambiguous figure. If this hypothesis is correct, such that activation of a particular visual representation is critical for producing a same-bias effect, then similar effects should be obtained if a representation can be activated through means other than the presentation of an unambiguous stimulus.

Some evidence consistent with this generalized activation hypothesis is provided by studies showing that context can bias a particular perception of an ambiguous stimulus. For example, the figure "13" can be perceived as the letter B or as the number 13 (i.e., the digits 1 and 3) depending on whether it occurs in the context of A and C or in the context of 12 and 14 (Bruner & Minturn, 1955). Additional evidence may come from studies demonstrating that observers can exert at least some degree of intentional control over the perception of reversible figures. For example, a number of investigations, including studies by Liebert and Burk (1985) and by Peterson and Gibson (1991), have shown that observers who are instructed to hold or maintain one perceptual configuration of a reversible figure can increase the percentage of time that they perceive the designated alternative.

Consistent with the generalized activation hypothesis, intentional control may be produced by voluntary retrieval and activation of a particular desired representation of the reversible figure. This idea can be traced at least as far back as Helmholtz who, in 1862, claimed that we can voluntarily perceive a reversible figure in a particular configuration if we simply recall vividly the image of the intended form. More recently, Suzuki and

Peterson (2000) suggested that "intentional control may operate by enhancing the relative activation of the desired representation" (p. 202). However, before intentional control of reversible figure perception can be taken as evidence for the activation hypothesis, we must consider the possible role of another, more peripherally based, mechanism of intentional control.

This alternative mechanism follows from what we will call the "focal feature hypothesis." Numerous investigators, including Gale and Findlay (1983), Garcia-Perez (1989), Kawabata (1986), and Tsal and Kolbert (1985), have presented evidence that certain sub-areas of a reversible figure are less ambiguous than others and therefore may bias one perceptual interpretation over the other. Which organization is perceived is determined by which subset of features receives focal processing. Reversals are thought to reflect shifts in focal processing from one set of critical features to another. And, the observer can voluntarily hold or maintain one perceptual alternative by constantly focusing on a single subset of features that favors the desired configuration. Thus, according to this hypothesis, an observer's intent determines the selection of features to receive focal processing, but it is the biased nature of those stimulus cues that actually determines the perceptual experience.

In an effort to clarify the mechanism of intentional control, we conducted an experiment with stationary Necker cubes in which we independently varied the fixation location within the cube and the instructions to hold or maintain a particular perceptual organization (Toppino, 2003). The focal feature hypothesis predicted that different fixation locations would bias different perceptual configurations. If intentional control over perception were also mediated by focal feature processing, the effect of intentionality should interact with the effect of fixation location in ways that will be discussed below, but, first, some methodological details are in order.

The focus of fixation within the Necker cube was varied among three locations (top right interior vertex, middle, and bottom left interior vertex). These locations were chosen because previous work indicated that they would differentially bias the perception of the two different orientations of the cube (e.g., Kawabata, 1986). For example, the top-right fixation was expected to bias a perception of the cube with its front face oriented down, whereas the bottom-left fixation was expected to bias a perception of the cube with its front face oriented up. There were also two intentionality conditions. The *No Hold* condition was a control condition in which observers were instructed to view the stimuli passively and simply report what they perceived. In the *Hold* condition, however, observers were instructed to try to hold or maintain a particular organization of the cube at all times. Half of the observers reported whenever they perceived the down orientation by pressing a response key and keeping it depressed for as long as that same configuration was perceived. The other half pressed the key to report whenever the cube was perceived to be in the up orientation. In an effort to avoid confusion and to simplify the demands of the task, observers in the Hold conditions voluntarily tried to maintain the same orientation as that on which they reported.

The results are shown in Figure 4 in terms of the percentage of time during the viewing session that observers perceived the cube to be in the down orientation as a function of fixation location and intentionality instructions. Figure 4a shows the data for those observers who were instructed to report whenever they perceived the cube to be in the down orientation. These data reveal an effect of fixation location such that the down orientation of the cube was perceived for a greater proportion of the viewing period when the fixation cross appeared in the top right of the cube. We also obtained an effect of hold instructions. Observers in the Hold condition were instructed to try to maintain the down orientation of the cube and, in fact, they perceived that configuration for a significantly greater percentage of the viewing period than did observers in the No Hold control condition.

Figure 4b presents the data for observers who were instructed to report whenever they perceived the cube to be in the up orientation; for comparison purposes, their data have been converted into time perceiving the down orientation. These data revealed the same effect of fixation location that was apparent in Figure 4a. There was also a comparable effect of Hold instructions. However, because these observers had been instructed to hold the up orientation, they perceived the down orientation for *less* time in the Hold condition than in the No Hold control condition.

The most important aspect of the findings, however, is that the effects of fixation location and intent were additive, as is quite apparent from the displayed data. That is, there was no hint of an interaction. We believe that these results are not compatible with the focal-feature-processing explanation of intentional control. In the No Hold conditions, in which observers did not make an effort to voluntarily control their perceptions, we obtained an effect of fixation location. This effect was predicted by, and is well explained by, the focal feature hypothesis. That is, directing focal processing toward the upper right interior vertex of the cube biases one to perceive the cube in a down orientation. If intentional control were also mediated by the locus of focal processing, intentional control and fixation location should have interacted. For example, when intent and fixation location biased different orientations, one or both of the effects should have been attenuated because presumably it is impossible to selectively attend to two different regions of the cube simultaneously. The additive results we

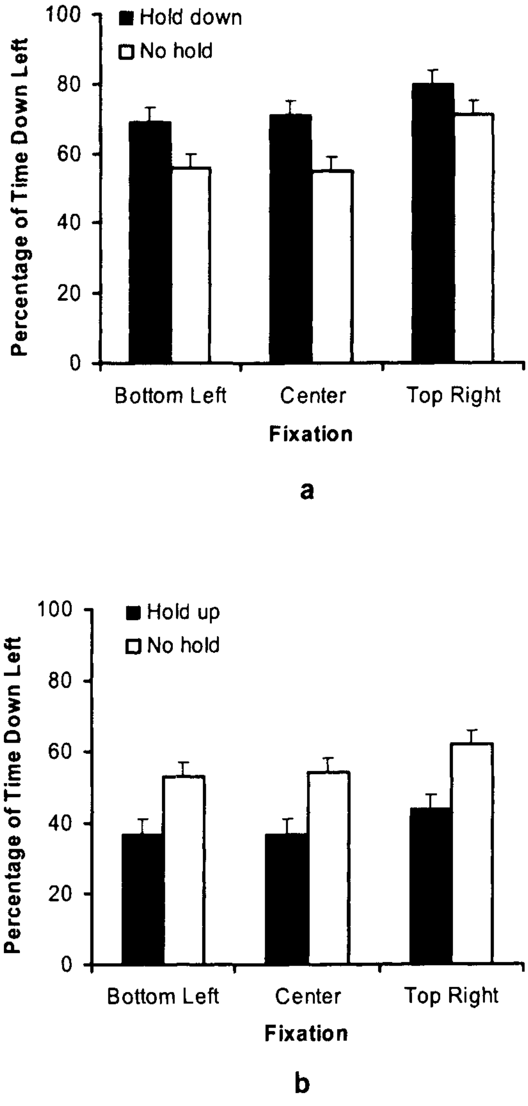

Fig. 4. Percentage of time during a 60-sec viewing period that observers perceived a stationary Necker cube to be in the down orientation as a function of fixation location and Hold vs. No Hold instructions. Data are presented separately for observers who held a response key down whenever they perceived the cube to be in the down orientation (a) and in the up orientation (b), respectively. In either case, observers in the Hold condition tried to maintain the orientation that they were reporting, that is, down (a) or up (b).

obtained suggest that the mechanism that mediated intentional control in our study was independent of focal-feature processing.

In a second experiment, we included a cube that was so small that we expected observers to have difficulty selectively processing one fixation location to the exclusion of the others (Toppino, 2003). When this tiny cube was viewed, the effect of fixation location was eliminated, which supports the assumption that the effect of fixation location reflects focal feature processing. Equally important, however, is the fact that viewing the small cube did not reduce the effect of Hold instructions at all. These findings provide strong converging evidence that the effects of Hold instructions are mediated by some independent mechanism. In that sense, our data are consistent with the hypothesis proposed most recently by Peterson and her colleagues (e.g., Suzuki & Peterson, 2000) that intentional control can be exerted by means of direct central activation or priming of the visual representation underlying the intended percept.

Although we did not make a point of it, there is another salient aspect of the data obtained in the last two experiments. Despite the fact that the intention to maintain a single percept produced large effects on the percentage of time that a given percept was experienced, observers were far from being able to exert perfect control. They perceived the stimulus to be in the *un*intended orientation for an appreciable amount of time. That is, the observers were apparently unable to prevent reversals from occurring. In fact, Hold instructions had surprisingly little effect on the number of reversals. This phenomenon has been reported in the literature before (e.g., Liebert & Burk, 1985), but it typically is left unexplained.

Our hypothesis is that observers' inability to voluntarily suppress all reversals is attributable to the influence of bottom-up processes that operate more or less automatically in reaction to stimulus characteristics. Therefore, we have initiated another series of experiments in which we simultaneously vary intentionality (Hold vs. No Hold instructions) and stimulus variables that are predicted to affect the rate of neural fatigue and, therefore, reversal rate. For example, the lines of a Necker cube can be intact, continuous lines or they can be represented as a series of dashes. Figures with intact lines yield faster reversal rates, presumably because they provide greater stimulation to the underlying neural channels, leading to a faster rate of neural fatigue (Babich & Standing, 1981).

Although this research is still in progress, the results to date suggest several conclusions. Both intentionality and stimulus variables appear to affect reversal rate. The reversal rate is slowed when an observer intentionally tries to hold one perceptual organization of a figure and also when figures provide less intense stimulation of underlying neural structures (e.g., when the lines of a Necker cube consist of dashes). The most interesting aspect of the findings, however, may be that the effect of stimulus variables is approximately the same regardless of whether observers are, or are not, trying to maintain a particular perceptual configuration. This suggests that the contributions of intention and stimulus variables affect figure reversal relatively independently. It also suggests that the limited control that observers exhibit over figure reversals may be at least partly attributable to the influence of relatively automatic, bottom-up processes.

A major point to be taken from our research on intentional control is that, once again, we are confronted with the simultaneous influence of top-down and bottom-up processes. Our findings suggest that intentional control over the perception of a reversible figure can be exerted by means of direct, top-down priming or activation of the desired visual representation. However, we also obtained evidence that a stimulus-driven process, such as neural fatigue, produces reversals that observers are apparently powerless to prevent.

Toward a Hybrid Model of Reversible Figure Perception

To summarize the findings presented above, we have obtained strong converging evidence that perceptual reversals are influenced by a bottom-up process of adaptation or fatigue of retinally-localized neural structures. We have also gained evidence for top-down influences by showing that figure reversals are affected by learning, by the subset of features to which observers attend, and by factors such as one's intentions and the presentation of an unambiguous stimulus, both of which seem likely to affect perception by activating particular underlying visual representations.

These findings have convinced us that an adequate explanation of reversible figure effects will require some sort of a hybrid model in which relatively passive, localized neural structures and higher-order cognitive processes both contribute to perceptual reversals. Figure 5 presents a theoretical framework within which we believe an adequate model of figure reversal can be developed (Long & Toppino, 2004).

Within this hybrid framework, we suggest that competing perceptual experiences are mediated at a "representational level" that is likely associated with structures located relatively high in the visual system. Thus, for example, one percept or the other may be able to be favored by intentionally-controlled, higher-order cognitive processes that affect the relative activation of the competing representations. The proposed location within the visual system is consistent with electrophysiological studies of percep-

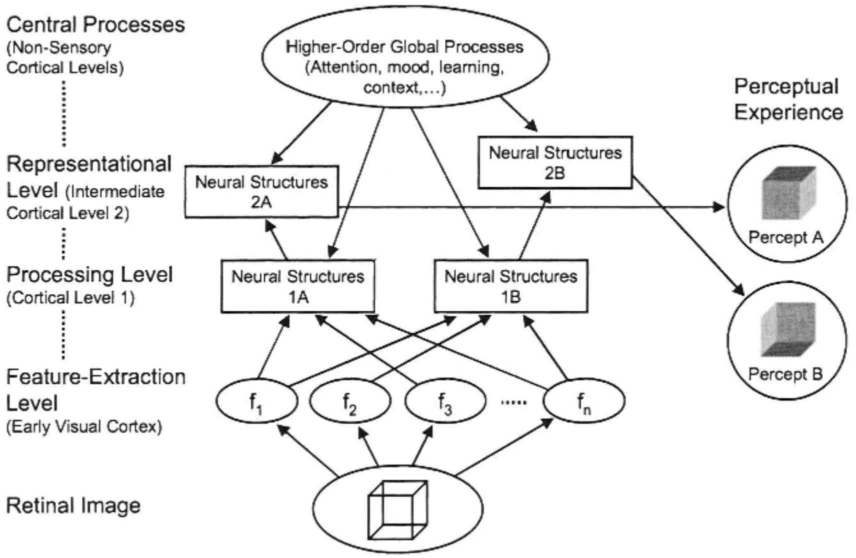

Fig. 5. Conceptual framework for a hybrid model of reversible figure perception.

tual instability which have shown strong correlations between alternating perceptual states and corresponding neuronal activity in areas such as IT, MT, the superior temporal sulcus (see Leopold & Logothetis, 1999, for a review) and, in the case of the face/vases figure, the fusiform gyrus (e.g., Andrews et al., 2002).

Bottom-up mechanisms, such as the fatigue and recovery of localized neural channels for which we have obtained so much evidence, seem likely to involve earlier structures in the visual system, possibly including activity in the striate cortex as well as in post-striate, pre-representational processing areas. Again, this assumption is consistent with recent electrophysiological work, including ERP research suggesting that reversals are associated with very early, low-level (e.g., occipital) processing (Kornmeier & Bach, 2004) and research using a variety of methods that suggests that even the earliest (e.g., striate) areas of the visual system may play a critical, and perhaps necessary, role in producing visual awareness (Tong, 2003).

The multi-leveled character of the hybrid framework explicitly allows interaction between different levels of the system. Thus, perception in general and figure reversal in particular would be expected to be the result of the likely complex interplay of higher- and lower-order processes within the system. Indeed, it has become common to conceptualize the visual system as involving many recurrent connections by which higher- and lower-order processes influence one another (e.g., DiLollo, Enns, & Rensink, 2000; Tong, 2003). Our proposed framework seems consistent with this conceptualization, although adequately representing it in Figure 5 would require the addition of many more connections among levels.

In concluding, we believe that this hybrid framework will be useful in guiding and constraining future theory and research. By encompassing both top-down and bottom-up processes, it avoids the either/or character of previous research on reversible figures. It encourages researchers and theorists to consider, within a single conceptual framework, findings that might otherwise seem incompatible. Most importantly, however, it encourages work addressing how top-down and bottom-up processes are coordinated, and how their effects are integrated, in producing the alternations in conscious perceptual experience that characterize figure reversals.

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Dynamic Uses of Memory in Visual Search Over Time and Space

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Summary. We review evidence on the use of one type of memory in visual search over time. Visual search benefits when observers are given a preview of distractors that remain throughout a subsequent search display. Studies examining negative carry-over effects and visual probe detection suggest that the 'preview benefit' is based at least in part on the inhibition of old groups of stimuli. However, the presence of luminance onsets defining the new search display are not necessary to produce the benefit, since, under appropriate conditions, a benefit can occur when the new stimuli do not have unique luminance onsets. Studies using functional brain imaging suggest that the inhibition of old groups of stimuli is modulated by the superior parietal lobe, whereas the detection of salient new targets is associated with activation in the temporo-parietal junction. Dynamic inhibition of memory representations of old stimuli provides a means of prioritizing attention to new events.

Key words. Visual search, preview paradigm, functional brain imaging

Introduction

In everyday life, our visual system is confronted with images that occur in a temporal context. Although unexpected events can occur, very often we have an expectation that a particular stimulus may be about to appear, and such stimuli will appear against the context of old objects that are already in the scene. How does the temporal context of prior events influence search for new items? Is search influenced by dynamic use of time-coded memories?

Recently there has been much controversy about whether memory processes have any influence on visual search. For example, Horowitz and Wolfe (1998) proposed that search is not affected by a memory for previously searched elements, whereas others have argued that processes such as 'inhibition of return' (IOR; Posner & Cohen, 1984), operating on at least a small number of memory representations, can play a role in guiding search (Danziger, Kingstone, & Snyder, 1998; Klein, 1988, 2000; see Horowitz & Wolfe, 2003, for a recent summary). Similarly, studies using change detection procedures have queried the robustness of memory for anything more than a small number of objects in visual displays (Simons, 2000; Rensink, 2000).

In contrast, studies in which some search displays are repeated throughout an experiment show that there is a benefit to search, contingent on the target maintaining its spatial location in relation to the locations of the distractors (e.g., Chun & Jiang, 1998). Also, studies using the 'preview paradigm' suggest that a memory for old stimuli can influence search (e.g., Watson & Humphreys, 1997). This paradigm provides a means of exploring search not only across space but also across time, as visual events change but some stimuli remain the same; hence, it is useful for assessing the role of the spatio-temporal context in search.

In this chapter, we review evidence from the preview paradigm suggesting that dynamic memory-based search operates across both time and space. These dynamic processes provide the observer with a flexible means of biasing search away from old and toward new events.

Preview search

To examine visual search over time as well as space, Watson and Humphreys (1997) adopted a classic color-form conjunction search task, so that one set of distractors (e.g., green Hs) was presented prior to the second set of distractors plus the target (when present; e.g., blue As and blue H target; see Figure 1). Compared to the situation in which all the items appeared together (the full-set baseline), search was facilitated in the preview condition (the preview benefit); indeed, search in the preview condition was as efficient as when only the second set of stimuli appeared (the half-set baseline). Apparently the old items had no impact on search.

To account for this result, Watson and Humphreys (1997) proposed that the old stimuli were actively inhibited, a process they termed "visual marking," which makes observers "attentionally blind" to these items. Under these conditions, selection is prioritized to the new stimuli and away

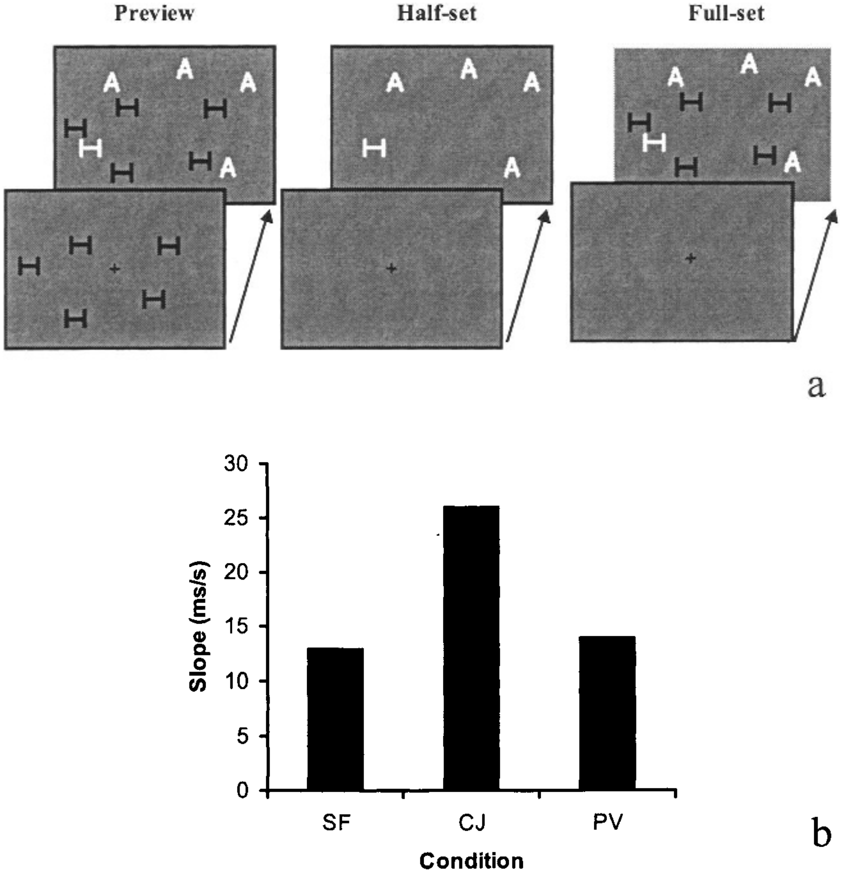

Fig. 1. (a) Example displays from Watson and Humphreys (1997) illustrating the preview search procedure. Black letters in the figure were green in the original displays, and white letters were blue. The target here is a white H (blue H in the original displays). (b) Plots of search rates (slopes of the RT/display size function) in the preview (PV), half (SF), and full set (CJ) baselines (just the new or the full final display).

from a memory representation of the old items. Furthermore, this is a time-consuming process so that the old items need to be in the field for some time before they can be effectively ignored (around 400 ms or so, in Watson & Humphreys, 1997). Consistent with the argument that there is an intentional component to prioritized search, the preview benefit decreased when observers performed a secondary task during the initial presentation of the preview (prior to the second, search display; see also Humphreys, Watson, & Jolicoeur, 2002; Olivers & Humphreys, 2002).

Other experimenters, however, have argued that any memory representation for the old stimuli plays little role in the preview benefit. For example, Donk and Theeuwes (2001) proposed that the benefit is due solely to attentional capture by the onsets of the new stimuli (cf. Yantis & Jonides, 1984). In a third account, Jiang and colleagues (Jiang, Chun & Marks, 2002) have argued that the benefit simply reflects temporal segmentation of the old stimuli from the new items. This segmentation process need not depend on the active maintenance and inhibition of a representation of the old items, but rather on temporal signals separating the two displays. Are either of these alternative accounts sufficient?

Negative carry-over effects and probe inhibition

Two reasons for arguing that onset-capture and temporal segmentation accounts are not sufficient to explain preview search are (i) the negative carry-over effects that can occur when old and new stimuli share features, and (ii) the pattern of results that occurs when probe detection tasks are combined with preview search. We consider negative carry-over effects first. Olivers and Humphreys (2003) examined negative carry-over effects from a preview on attentional capture from new singletons. When participants are asked to search for a relatively low-salient target, performance can be disrupted by an irrelevant, salient, singleton distractor. For example, in Theeuwes (1992), search for a shape-defined target was disrupted by the presentation of a distractor whose color differed from the color of the other items in the display (a color singleton). Such a result is consistent with attention being captured in a bottom-up manner by a salient stimulus.

Olivers and Humphreys used search displays which could contain a singleton distractor, but preceded these by a preview display in which the old items carried the feature value of the singleton (e.g., its color or its orientation; see Figure 2). If there was attentional capture by the new onsets, or temporal segmentation and selection of the new stimuli, then singleton distractor effects should be as large as in a single-set baseline condition, where only the new items are presented. In contrast to this, the effect of the singleton distractor was greatly reduced by the presence of the preview (see also Braithwaite & Humphreys, in press).

In control conditions, Olivers and Humphreys showed that this result was unlikely to be due to neural fatigue to the feature values in the first display. For example, if a set of colored stripes formed the background of

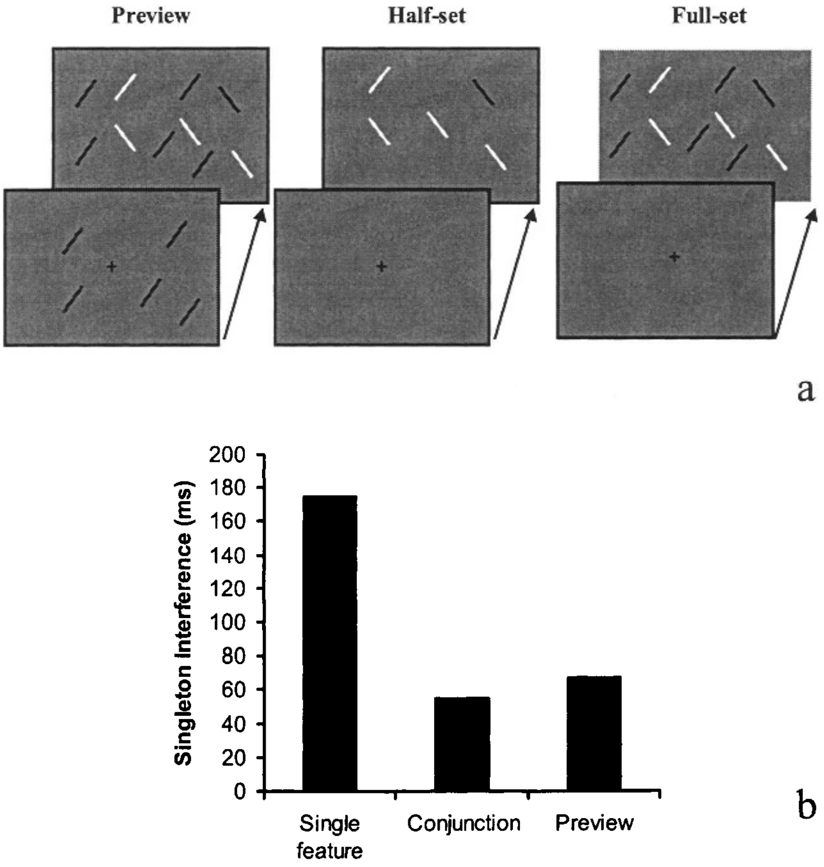

Fig. 2. (a) Example stimuli from the Olivers and Humphreys (in press) study of preview effects on 'singleton capture'. In this example, the target is a line sloping 45° to the right and the task would be to make a discrimination response based on a property of this stimulus (e.g., is there a gap in the line). In the figure, there is a color singleton distractor (black line, sloping 45° to the left) in the search display. The items presented in the search display in the half-set baseline are identical to those presented as new items in the second display in the preview condition. (b) Magnitude of the interference effect from a distractor in a singleton color in a search display, in baseline (single feature and conjunction) and preview search conditions. Here we plot the difference in RT between responses to an orientation-defined target when a color singleton distractor was present, compared with performance in the same conditions when the color singleton distractor was absent.

the preview, there was little carry-over based on the color or orientation of the stripes—thus the presence of the critical feature in the display was not critical by itself. Rather, to generate a negative carry-over effect, the feature values needed to be present in preview items that could compete with the subsequent target, and hence had to be ignored in search. The effect was also not due to feature-based grouping between the new and old items, once the new items had been presented (a process that might operate in opposition to temporal segmentation). This follows because the negative carry-over effect remained even if the preview display was removed on the presentation of the new search items, so that grouping could not operate across the displays. In addition, the carry-over effects decreased when the preview was presented for a reduced duration, consistent with there then being insufficient time to inhibit short-duration previews.

Similar results have been reported by Braithwaite and Humphreys (2003; in press; Braithwaite, Humphreys, & Hodsoll, 2003). They examined search in displays where the items can appear in one of two colors, with the colors distributed unevenly across the items present (to form majority and minority color groups). When all of the items appeared simultaneously, there was a bias to find a target in the minority color faster than in the majority color—presumably reflecting the informativeness of the minority color for predicting the target (see also Egeth, Virzi, & Garbart, 1984; Kaptein, Theeuwes, & van der Heijden, 1995). However, this bias could be completely reversed if the minority color in the search display was carried by the majority of the items in the preview display (see Figure 3). Braithwaite and Humphreys (2003) suggested that there was inhibition of the largest group in the preview, with this inhibition being carried over to stimuli with matching feature values in the search display. Due to their being inhibited, new targets in the minority color are difficult to discriminate. As in Olivers and Humphreys (2003), this carry-over effect decreased when the preview was presented for a shorter duration, but it remained if, after a long duration preview, the old items were removed on presentation of the new.

These data on negative carry-over effects are complemented by experiments using probe detection procedures to examine the allocation of attention during search. Watson and Humphreys (2000) had participants perform a standard preview search task on the majority of trials. However, on a minority of trials, an auditory tone signaled a change of task, with participants then having to detect a brief visual probe that could appear on either a new or an old stimulus. They found that probes falling at the locations of old items were difficult to detect relative to probes falling at the locations of new items, with detection at the location of old probes being considerably worse than the detection of probes falling on the same stimuli

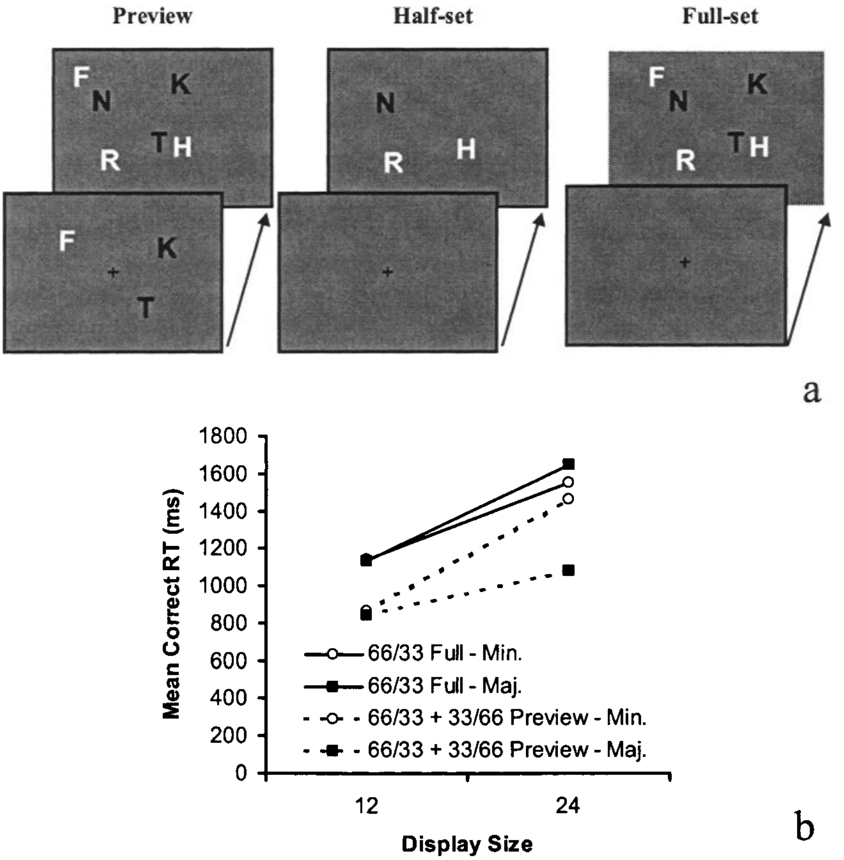

Fig. 3. (a) Example stimuli from the Braithwaite and Humphreys (2003) study of search biased to color groups. The task was to discriminate which of two target letters (N or Z) was present in the search display. The black and white letters in the figure were red and green letters in the displays. In the example, there is a majority of black letters in display 1 of the preview, and a majority of white letters in the search display in the preview condition and in the half-set baseline. This means that there are an equal number of white and black letters in the final overall display in the preview condition and in the matched full-set baseline. (b) Mean RTs to targets in a minority or majority color group in a search display, in a full-set baseline condition (no preview) and in a preview search condition. In the preview condition, the balance of the color groups is the opposite to that in the search display. Note that there is a benefit to being in the majority new color in the preview condition, and a cost to being in the majority new color in the baseline.

in a conjunction baseline condition (where all the items appeared simultaneously). Similar data are reported by Humphreys, Jung-Stalmann, and Olivers (in press a) and Olivers and Humphreys (2002). Humphreys et al. used colored rectangles which were created by changing the color of contours in a background grid (Figure 4). They showed that probes falling within the boundary of old stimuli were more difficult to detect not only than probes appearing in new items but also than probes falling in the "neutral" background regions between the shapes. The difference in detection at "old" and neutral locations occurred even when probes were presented before the appearance of the new stimuli. This contrast, between detection on old items and detection in a neutral condition, is consistent with the old items being inhibited.

The poor detection of probes on old items is also not simply due to the presentation conditions. In baseline conditions in probe studies, participants have been asked only to perform the probe detection task rather than searching for a new target on a majority of trials. Differences in detection at old and new locations are then minimized (Humphreys et al., in press a; Olivers & Humphreys, 2002; Watson & Humphreys, 2000). It appears that observers have to adopt a set to search the new items, and to ignore the old stimuli, to generate the bias in selection.

Recently, Braithwaite, Humphreys, and Hulleman (in press) combined probe detection with a study of negative carry-over effects in search. Probes (occurring on a minority of trials) could fall either in the majority or minority group, on either an old or a new item. In the preview condition (Figure 3), the detection of a probe on a new item was harder if the new item shared its color with the majority of the preview items, even if it was the minority color in the new display. Probes were even harder to detect if they fell on old items, with performance being worse when it fell on items in the majority group in the preview. These results are consistent with there being inhibition of the majority group in the preview, which can be carried over to new stimuli with the same featural properties.

Braithwaite et al. (in press) went on to examine effects of changing the colors of the old items, when the new stimuli appeared. For example, 66% of the items in the preview might be red and 33% green. These might be followed by a search display where 66% of the items are green and 33% red, with the target being equally likely in either group. On the presentation of the new search items, the stimuli in the preview could also change (respectively) to blue and yellow. There were two particularly interesting effects. First, there remained poor detection of probes on new items if those new items carried the color of the majority of the stimuli in the preview (e.g., if the new target was red, in the above example). This arose

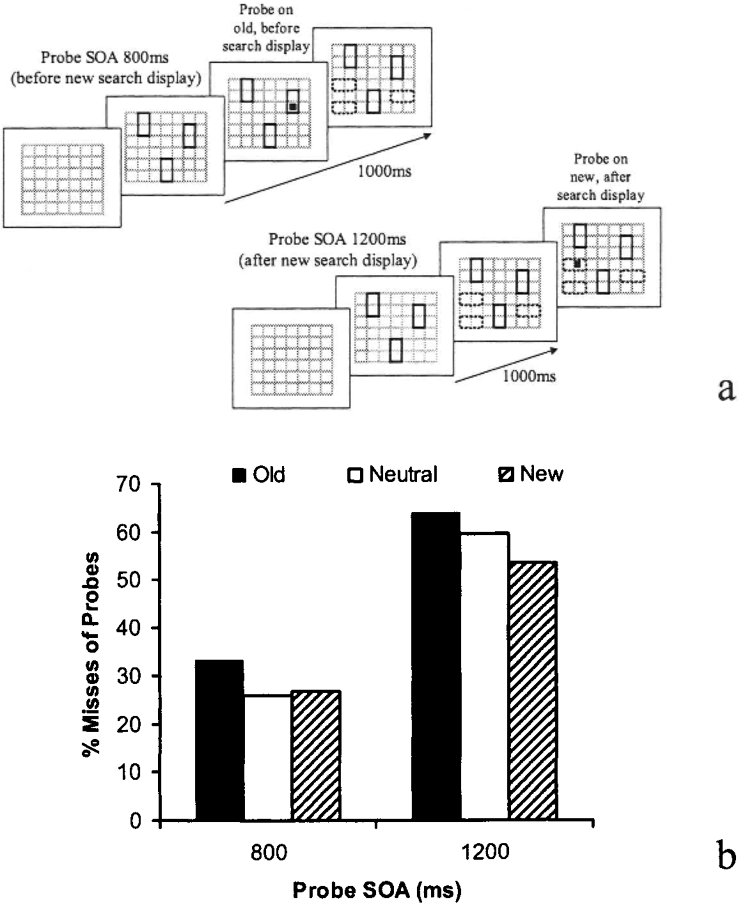

Fig. 4. (a) Example displays from Humphreys et al. (in press a). Both examples are of target absent trials, where only distractors (black, vertical rectangles and striped, horizontal rectangles) are shown (target = striped, vertical rectangle). A probe dot was presented either before or after the search display (stimulus onset asynchrony [SOA] = 800 or 1200 ms, respectively), and the dot could appear either within an old object, within a new object, or in a background square in the grid. After making a reaction time response in the search task, participants were asked to decide whether a probe dot had appeared. In the experiment, the stimuli were shown against a black background screen. The grid area was blue, and the black rectangles were green and the striped rectangles were red. (b) Detection accuracy for probes presented in old objects, new objects, or neutral locations, with probes presented either 800 or 1200 ms after the preview. The preview appeared for 1000 ms before the appearance of the search display.

despite the old items no longer having that color when the new stimuli appeared, ruling out the possibility that such targets grouped with the majority of items in the preview on the basis of their shared color. The finding is consistent with inhibition of feature values for stimuli in the preview. Second, there was poor detection of probes falling on old items, and this effect was most pronounced for probes on items that were in the majority color (e.g., the items that were formerly red but then changed to blue). This result cannot be attributed to feature-based inhibition, because the features of the old items changed (hence the old items should no longer have been inhibited). Instead the data suggest that the old items were inhibited as a group, and this group remained inhibited even when there was a color change across all its members.

Duncan and Humphreys (1989) proposed an account of visual search stressing the role of grouping both in selecting a target and in rejecting distractors. They posited that distractors could be rejected as a group by a process of "spreading suppression" based on the similarity of feature values. Such a process would lead to the suppression of old items in preview search. Moreover if the spreading suppression process operated multiplicatively, then there would be greater suppression of members of a larger relative to a smaller group.. This would fit Braithwaite et al. (in press) data.

Taken together, these data support the argument that preview search is based on more than either attentional capture by new onsets or temporal segmentation. Rather, there is inhibitory rejection of old items. There appears to be inhibition of old distractor groups and of the locations occupied by group members (given that probes falling at old locations are inhibited). In addition, there seems to be associated inhibition of the feature values carried by group members, which is carried over to affect the processing of stimuli with the same features in subsequent displays.

Search with isoluminant stimuli

One of the reasons for Donk and Theeuwes (2001) proposing that only onset capture was important in preview search was that they found that old items did influence preview search when the new stimuli were isoluminant with their background. They reasoned that, to be prioritised for selection, the new items had to be created by luminance onsets. However, other work suggests that this is not necessarily the case. As noted above, Humphreys et al. (in press a) used conditions in which the shapes of the stimuli were created by changing the colors of contours in a background grid. The colors making up the grid and the shapes were matched for luminance for individual observers and, in addition, random luminance changes (brightening or darkening individual pixels by 10% of their fixed luminance values) were added to elements in the grid and/or the shapes. Under these conditions, it is highly unlikely that the new stimuli are defined by luminance onsets. Nevertheless, there was a preview benefit relative to a full-set baseline. Apparently, creating the stimuli from unique onsets is not necessary to generate a preview effect.

One of the differences between the displays used by Donk and Theeuwes (2001) and those used by Humphreys et al. (in press a) is that, in Donk and Theeuwes, the individual stimuli were isoluminant with their background. In Humphreys et al. the stimuli were not isoluminant with the background, but they were with the grid and the other shapes present. Previous work has shown that it is difficult to process the locations of stimuli isoluminant with their background (Livingstone & Hubel, 1988). It may be that this is important for the preview effect if any inhibition operates through the locations of the stimuli (guided by grouping), and if there is location-based selection of new stimuli.

We have examined these possibilities by measuring preview search when new items are isoluminant with their background. Under standard search conditions (e.g., with previews presented for about 1 sec before the new stimuli), we found a preview benefit (relative to a full set baseline) provided that the old items were not isoluminant with the background (i.e., provided that the locations of the old items could be coded efficiently; Braithwaite, Humphreys, Watson, & Hulleman, 2004). Furthermore, when a prolonged preview period was used (with a preview of 3 sec; see Figure 5), a preview benefit occurred when both the old and the new stimuli were isoluminant with the background. We suggest that, under prolonged viewing conditions, the locations of preview stimuli can be coded, enabling old items to be rejected from search.

The relations between visual marking and other attentional processes

If there is a case for the inhibitory process of visual marking, then we can also review the relations between marking and other mechanisms influencing visual selection, such as IOR (Posner & Cohen, 1984) and negative priming (Tipper, 2001). Olivers, Humphreys, Heinke, and Cooper (2002) assessed whether IOR, serially applied to each old item, was responsible for the preview benefit. They used a variation of the preview search task in which the target could appear in either the first or second display. The task

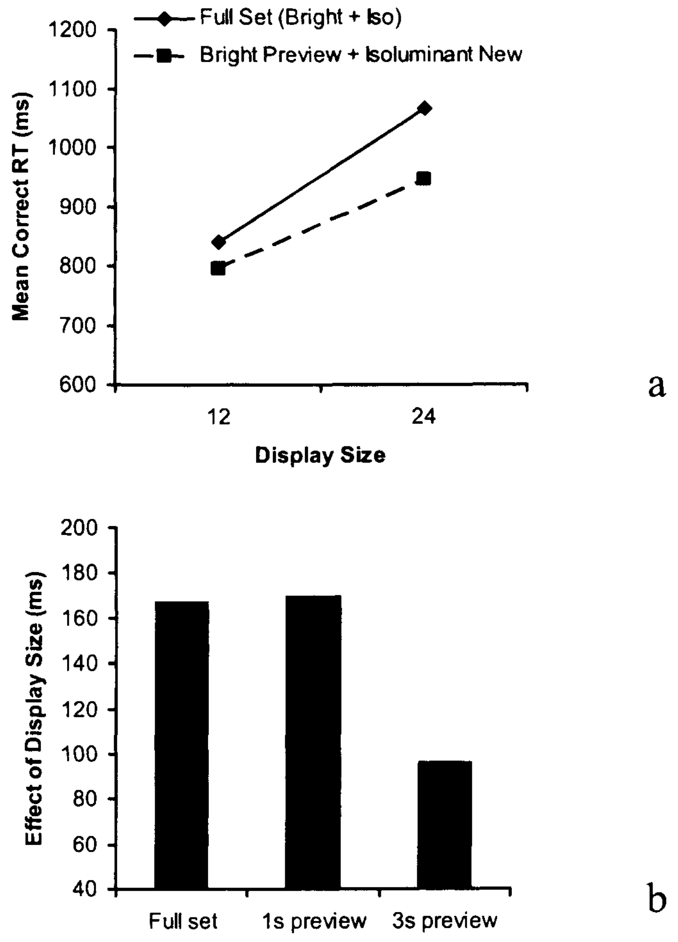

Fig. 5. (a) Data from Braithwaite et al. (2004) for search for a target that was isoluminant with the background presented after a non-isoluminant preview; displays in the full-set baseline matched the final display in the preview condition (having a mixture of isoluminant and non-isoluminant items, with the target always being isoluminant). (b) Data from Braithwaite, Watson, and Humphreys (in preparation) for search where all of the items are isoluminant with the background, in a full-set baseline condition and in a preview search condition with previews presented for either 1000 ms or 3000 ms. The results are plotted in terms of the reaction time cost due to increasing the display size from 8 to 16 items in the final search display.

was to discriminate a letter target that appeared among random letter distractors, so that a serial search was always required. If the target was not present in the first display, participants had to make a button press to expose the second display. Thus, when the target was in the second display, there should have been maximal IOR applied to the old stimuli, before the new items appeared. However, despite this, there was only a minimal benefit for the preview condition relative to a full set baseline where all of the items occurred together, and performance was considerably better in a standard preview condition where the target was expected to be in the second display.

This pattern of results indicates that visual marking is not simply the serial application of IOR to the old stimuli. Of course, there are also grounds for arguing that IOR itself is not a unitary process. For example, spatial IOR may be separated from an object-based process (Tipper, 2001), and it may be that object-based IOR is similar to visual marking—note that the evidence from Braithwiate et al. (in press) suggests that marking is applied to groups of old items, so that grouping seems essential to the mechanism.

What about negative priming? Tipper (1985) first proposed that, when we have to select one stimulus and reject another, the rejected item is inhibited, with this inhibition remaining over time to influence later processing (see DeSchepper & Treisman, 1996, for evidence on long-lasting negative priming effects). Negative priming may operate on a variety of stimulus properties (locations, features), depending on which are relevant to the task (see Tipper, 2001, for a review). Olivers and Humphreys (2002) interspersed preview search trials with trials in which observers responded to a single display where the stimuli could have the properties of the preview on the previous trial. They found that search in this baseline condition was slower when participants attended to the earlier preview (and appeared to inhibit it) compared with when a secondary task was presented to reduce attention (and inhibition) being applied to the preview. These data illustrate that at least some forms of negative carry-over effect from the preview can be robust across separate trials, and that such effects are contingent on the allocation of attention (and inhibition) to the preview. This feature-based inhibition may be the same as negative priming. To test such speculations, we may need to probe the underlying neural substrates of marking, IOR, and negative priming. It is to studies of the neural underpinnings of marking that we now turn.

The neural substrate of preview search

There have now been several studies where investigators have attempted to assess the neural substrates of the processes involved in preview search. Humphreys et al. (in press b) used PET to measure brain activity across blocks of search where the duration of the preview display varied. Activity in a search condition was compared with a baseline in which the same stimuli appeared but participants just had to respond to the appearance of the second display (matching for the visual conditions and for any temporal expectancies). Behavioural measures showed that search for the target became easier as the preview was presented for longer durations. Activation in the superior parietal lobe was greater in the search relative to the baseline condition, and this difference increased as the preview duration lengthened (showing the opposite pattern to the measure of the search difficulty). This result suggests that the superior parietal activity was not a reflection of search, but rather of a representation of the old items, one that was encoded across time. Pollmann et al. (2003) used fMRI and also found increased and earlier activation in the superior parietal lobe in the preview relative to single feature and conjunction search conditions. This earlier activation was present even on "dummy" trials on which no search displays were presented after the preview.

These last two studies suggest that in preview search subjects code a representation of the old items in the superior parietal lobes—a brain region that likely contains a spatial map of occupied areas of visual field (cf. Ungerleider & Haxby, 1994; Ungerleider & Mishkin, 1982). This same area might also be the locus of any inhibition of old items, or it might modulate any inhibition applied to another brain region. In the study of Pollmann et al. (2003), there was a second area of activity that showed increased activation relative to conjunction baseline, but this was not linked to processing the preview but rather to the ease of search—activation in the temporal-parietal junction (TPJ) was enhanced in both the single feature and the preview conditions. This TPJ activity likely reflects the allocation of attention to a salient new target, a process common to the single feature and preview search conditions. Apparently, the coding of the preview (in the SPL) is separate from any consequences of this coding on subsequent search (in the TPJ, sensitive to changes in the saliency of the search target).

In these imaging studies, there was some suggestion that activity in the right SPL was particularly important for preview search. This distinguishes the activity from that found in studies where purely temporal expectancies have been examined. For example, Coull and Nobre (1988) report activity in the left inferior parietal lobe and the left inferior premotor cortex under temporal cueing conditions (see Nobre, 2001, for a review). This is consistent with preview search stressing spatio-temporal segmentation, rather than temporal segmentation alone (cf. Jiang et al., 2002).

Neuropsychological studies converge with the imaging evidence in indicating that the parietal activity is necessary to preview search. Olivers and Humphreys (in press) examined patients with unilateral parietal lesions while they performed single feature, conjunction and preview search tasks. They found that preview search was selectively impaired in the patients, with performance being no better than the conjunction baseline. This selective deficit was most pronounced when the old and new items were spatially overlapping, and performance improved if the old and new stimuli fell in different visual fields (even when the old items appeared in the 'good', ipsilesional field and the new stimuli in the impaired, contralesional field). Note that any problems in the patients disengaging spatial attention from the old to select the new stimuli should be greatest in this last condition (cf. Posner, Walker, Friedrich, & Rafal, 1984). In contrast to this, the results suggest that the patients had most difficulty when the demand on spatial segmentation increased. This fits with the idea that the patients were impaired either at developing an accurate spatial map of the old stimuli or in using this map to increase the salience of the new relative to the old stimuli.

Conclusions

The work on preview search indicates that a memory for old stimuli can play an important part in facilitating visual selection for new stimuli. When participants are looking for a target in a new search display, they can adopt a set in which memory representations of old stimuli are de-prioritized for selection. This de-prioritization process (visual marking) seems to involve the encoding and subsequent suppression of groups of old items, biasing attention away from their locations. This process is modulated by the SPL. The inhibition also appears to apply to the features of the old group, and this feature-based inhibition can affect the processing of subsequent stimuli carrying the same feature values. As a consequence of old items being inhibited, the signal-to-noise ratio can be increased for new stimuli, enhancing their selection. The TPJ is sensitive to the saliency of stimuli in the field, and may serve to direct attention to new targets (see also Corbetta & Shulman, 2002, for a similar view).

The evidence that marking is applied to groups of old items can also help to reconcile any apparent contradiction between what appears to be a substantial memory representation involved in marking and the evidence for much more limited memory representations found in studies of change blindness (Rensink, 2000). To date, the limits of visual marking have not been established, but effects have been found with up to 15 old and new items (Theeuwes, Atchley, & Kramer, 1998). In contrast, only around 4 or so items seem to be represented for change detection across sequentially presented displays. However, if marking operates on groups, then the old items may be rejected without apparent capacity limits if they are chunked together. This chunking process is likely sensitive to a number of factors—common color (Braithwaite et al., in press) but also spatial configuration (Kunar, Humphreys & Smith, 2003; Takeda & Kumada, 2004) and even common onsets. Temporal grouping and segmentation may be necessary (even if not sufficient) for generating efficient search over both time and space.

In general, the work indicates that the human attention system can take advantage of temporal differences between visual stimuli to optimize selection. It does this not only by prioritizing new events, but also by deprioritizing old events. In this sense, time may provide an additional cue, much as other visual features such as color, motion, or shape, to help partition the relevant from the irrelevant, using both excitatory and suppressive processes.

Author Notes

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Memory for Information Perceived Without Awareness

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Summary. What is the duration of the influence of information perceived without awareness? Some studies suggest a duration of only a few seconds whereas others suggest a duration of hours, days, or weeks. To further investigate this question, we used a variant of the inattentional blindness paradigm (Mack & Rock, 1998). In three experiments, participants viewed briefly presented visual displays consisting of both a centrally located word and a peripherally located cross with unequal vertical and horizontal arms. Awareness of the words was varied by requiring participants either to read the word and then judge which arm of the cross was longer, or the reverse. Perception of the words was assessed using three-letter stems (e.g., pho_ __) of each word (e.g., phone), with participants instructed to complete the stem to make any word other than one previously presented. Success in following the instructions indicates that a word was perceived *with* awareness; failure indicates that a word was perceived *without* awareness. Memory for information perceived without awareness lasted for at least 32 minutes, and was strong following all retention intervals. These findings are consistent with previous studies suggesting that memory for information perceived without awareness can last for hours or days.

Key words. Awareness, memory, consciousness, anaesthesia,, inattentional blindness

Introduction

What is the duration of information perceived without awareness? This is a critically important question. Given that perception without awareness is now a firmly established phenomenon (see Merikle, Smilek, & Eastwood, 2001), an answer to this question is relevant for deciding just how important an influence perception without awareness may be on the way people consciously experience the world. If the influence of perception without awareness only lasts for a few seconds, then perception without awareness may not have particularly important consequences. In contrast, if the influence or impact of perception without awareness lasts for hours or days, then perception without awareness may have important consequences regarding how people consciously experience the world about them.

In this chapter, we first describe a series of experiments in which the duration of the impact of information perceived without awareness was assessed over retention intervals ranging from a few seconds to 32 minutes. The results of these experiments show that information perceived without awareness persists in memory for at least 32 minutes, and suggest that information perceived without awareness may persist in memory for considerably longer periods of time. We next review the evidence from studies of memory for information presented to surgical patients during general anaesthesia. The results of these studies show that memory for information perceived without awareness can last for hours or even days following surgery. Thus, the evidence from two very different types of studies shows that information perceived without awareness can persist in memory for considerable periods of time.

Finally, we consider why the findings from other studies (e.g., Greenwald, Draine, & Abrams, 1996) suggest that the impact of information perceived without awareness may only persist in memory for periods of time lasting no more than a second. We suggest that these very different conclusions are the consequence of the way awareness is measured. In our studies and in studies of memory for events during anaesthesia, awareness was assessed using subjective measures, whereas in other studies, awareness has been assessed using objective measures. We suggest that subjective measures provide a more accurate measure of the presence or absence of awareness than is provided by objective measures.

Studies of memory for information perceived without awareness

Our studies were based on a methodology adapted from Mack and Rock's (1998) studies of inattentional blindness. Figure 1 shows examples of the displays used by Mack and Rock in many of their studies. On each trial, participants viewed a series of three displays: fixation, stimulus, and mask. Each stimulus display contained a cross with either a longer vertical or a longer horizontal arm presented in one of the quadrants. Both the location of the cross and the arm which was longer varied randomly on each trial.

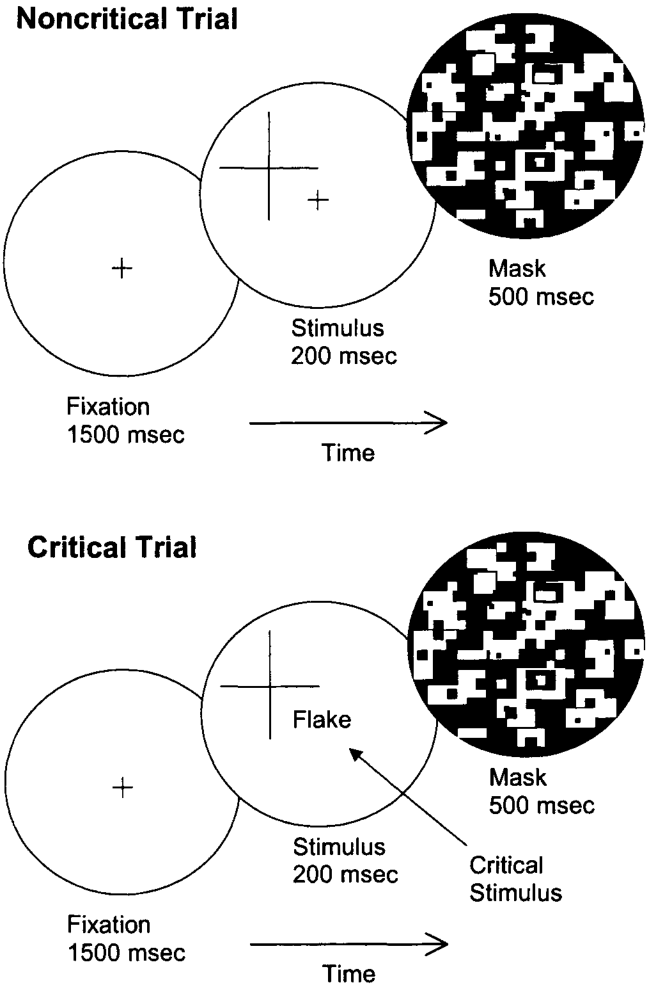

Fig. 1. Illustration of the stimulus displays used by Mack and Rock in many of their studies of inattentional blindness (adapted from Mack & Rock, 1998, p. 16).

The participants' task was simply to state which arm of the cross (i.e., horizontal or vertical) was longer. In a typical experiment, the first two trials in a series of three trials would be noncritical trials with only a cross in one quadrant of each stimulus display. On the third or critical trial, in addition to the cross, each stimulus display also contained a critical stimulus presented at fixation (e.g., a word). On all critical trials, once the participants indicated which arm of the cross was longer, they were asked if they had seen anything other than the cross on the trial. Surprisingly, across a number of experiments, anywhere from 50 to 60% of the participants *failed* to notice the critical stimulus at fixation. It is these failures to notice critical stimuli that defines inattentional blindness.

Mack and Rock (1998) conducted a series of experiments in which a single word was presented at fixation on critical trials. On average, 62.5% of the participants failed to notice the word. Mack and Rock interpreted this finding as indicating an absence of any conscious awareness of the words. They then sought to determine whether there was implicit knowledge of the words despite the participants' failures to notice the words. To test for implicit knowledge, Mack and Rock used the stem-completion task. On critical trials, once a participant indicated which arm of the cross was longer and stated whether they noticed anything in the center of the display, Mack and Rock presented the three-letter stem of the word presented on that trial. For example, if the word *flake* had been presented, then the word stem that followed was *fla* _ _. The participants were asked to complete the word stem with the first two words that came to mind.

Not surprisingly, the results indicated the 95% of the participants who noticed a word on the critical trial used it as one of their stem completions. More importantly, 36% of the participants who claimed not to have seen a word or any other stimulus at fixation on the critical trial also used the word to complete the stem. Given that the baseline level of performance for completing the stems with the critical words was 8%, these findings indicate that the participants had some implicit knowledge of the critical word even when they claimed not to have seen it. Thus, the results of these experiments provide strong evidence that at least some of the critical words were perceived without awareness.

Our experiments had two important differences relative to the experiments conducted by Mack and Rock (1998). First, in the majority of Mack and Rock's experiments, there was a single critical trial. This was to ensure that conditions of inattention were met. In contrast, we presented each participant with multiple critical trials. Mack and Rock assumed that conditions of inattention must be met to ensure that participants were unaware of the critical stimuli. However, conditions of inattention are not *necessary* for perception without awareness to occur. Merikle and Joordens (1997) showed that simply dividing participants' attention is sufficient to produce perception without awareness. Thus, as long as attention is divided between the cross and the critical stimulus, it should be possible to examine perception without awareness using multiple trials and displays similar to those used by Mack and Rock.

The second important difference between our experiments and Mack and Rock's experiments was that we assessed memory with a stem-completion task coupled with exclusion instructions rather than with a stem-completion task coupled with instructions asking participants to complete the stems with the first word that came to mind. With exclusion instructions, participants are asked to complete the stems with any word other than a word that they may have seen in the stimulus displays. The basic assumption underlying exclusion instructions is that whenever a critical stimulus word is perceived with awareness, participants will follow the instructions and not use the word to complete a stem. In contrast, whenever a critical stimulus word is perceived without awareness, participants may use the word to complete a stem because they have no awareness of ever having perceived the word during the experiment. Exclusion instructions have been used successfully in previous experiments to distinguish perception *with* awareness from perception *without* awareness (e.g., Merikle, Joordens, & Stolz, 1995). Perception *with* awareness is implied whenever participants successfully follow the instructions and do not use the words in the displays to complete the stems. An important consequence of following the exclusion instructions is that the number of failures to follow the instructions falls *below* the baseline level of performance. In contrast, perception *without* awareness is implied whenever participants fail to follow the exclusion instructions and use the words in the displays to complete the stems. The consequence of not following the instructions is that the number of failures to follow the instructions is *above* the baseline level of performance.

The real advantage of using a stem-completion task in conjunction with exclusion instructions is that perception *with* awareness and perception *without* awareness lead to different patterns of findings relative to the baseline level of performance. Perception *with* awareness leads to performance below the baseline level, whereas perception *without* awareness leads to performance above the baseline level. These qualitatively different patterns of data make it relatively easy to distinguish conditions which lead to perception with awareness from conditions which lead to perception without awareness. In contrast, when participants are simply asked to compete stems with the first word that comes to mind, it is not possible to distinguish perception with awareness from perception without awareness because both types of perception lead to increases in the number of word stems completed using words that appeared in the stimulus displays. It is for these reasons that we used a stem-completion task coupled with exclusion instructions in our studies investigating memory for information perceived without awareness.

In our first experiment, the goal was simply to establish whether our adaptation of the Mack and Rock (1998) methodology could be used to study perception without awareness. Figure 2 shows examples of the trial se-

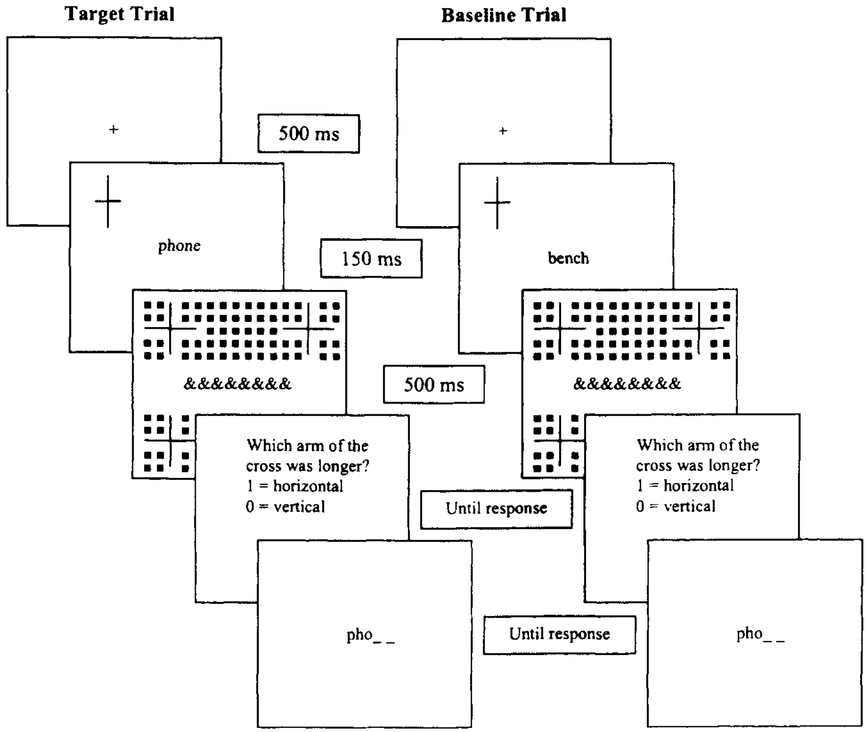

Fig. 2. Examples of the sequence of events on target and baseline trials.

quences used in this study. On each trial, a single display containing both a peripherally located cross and a centrally located, five-letter word was presented for 150 ms. The participants were instructed to perform two tasks. Half of the participants were instructed to first read the word and then to decide, if possible, whether the horizontal or vertical arm of the cross was longer. For these participants, the instructions placed the primary emphasis on reading the words and the expectation was that the participants would perceive most if not all of these words with awareness. In contrast, for the other half of the participants, the instructions were reversed: These participants were instructed to first decide which arm of the cross was longer and then to read the word, if possible. Given previous findings showing that divided attention leads to perception without awareness (e.g., Debner & Jacoby, 1994; Merikle & Joordens, 1997), it was expected that in many instances the words would be perceived without awareness because the primary emphasis was placed on judging the arms of the cross.

Following the presentation of each display, the participants were presented with two tasks. First, as shown in Figure 2, they were asked to decide whether the horizontal or vertical arm of the cross was longer. Once the participants made their decision regarding the cross,, they were presented with a three-letter stem. On target trials, the stem consisted of the first three letters of the word that had been presented in the display. On baseline trials, the same three-letter stem was presented but it was preceded by a word other than the target. All participants were instructed to complete the stems to make any five-letter word except a word that had been presented in the stimulus displays. The expectation was that perception of the words with awareness would bias participants not to use the words to complete the stems, whereas perception of the words without awareness would bias participants to use the words to complete the stems.

The results of Experiment 1 are shown in Figure 3. The dotted line in the figure indicates how often the word stems were completed to make the target word on baseline trials when the target word was *not* presented. As indicated in the figure, the baseline completion rate was approximately 21%. Relative to this baseline, it can be seen that when the participants focused their attention on the target words (read words first), they were very successful in excluding the target words from their completions of the word stems. On these trials, the stems were completed with target words significantly less often than the stems were completed with target words on baseline trials. Given the logic underlying the exclusion instructions, this finding indicates that when the participants focussed their attention on the target words, they were generally aware of the target words. In contrast, it can also be seen in Figure 3 that when the participants focussed their attention on the crosses (judge cross arm length first), they failed to exclude the target words from their stem completions on more than 35% of the trials. The participants used target words to complete the stems on these trials significantly more often than they completed the stems on baseline trials with target words. The logic underlying the exclusion instructions leads to the conclusion that the target words were perceived without awareness on many trials.

The pattern of results found in Experiment 1 shows that it is possible to use a multi-trial adaptation of Mack and Rock's (1998) methodology to study perception without awareness. In a manner consistent with previous findings (e.g., Debner & Jacoby, 1994; Merikle & Joordens, 1997), when the participants read the target word and then judged which arm of the cross was longer, they generally were able to show that they were aware of

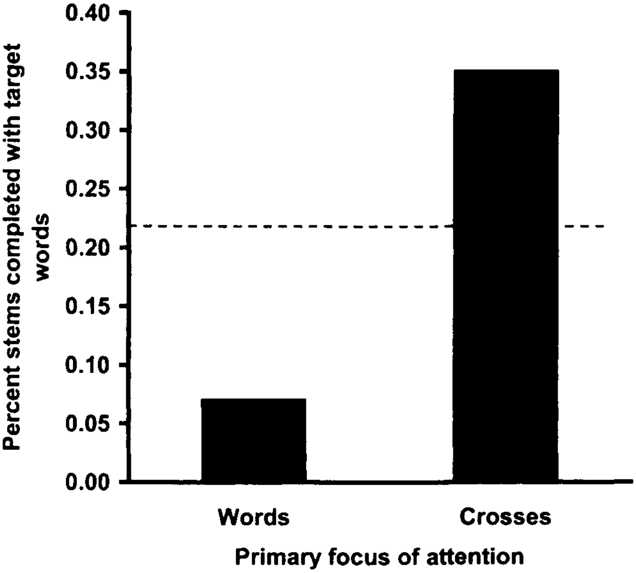

Fig. 3. Experiment 1: Percent of stems completed with target words when attention to the displays was focussed on the words and on the crosses. Dotted line indicates the baseline level of performance.

the target word by completing the word stem with a word other than the target word. In contrast, when the participants first judged which arm of the cross was longer and then attempted to read the word, they were often unable to exclude the target words as completions for the word stems. This pattern of findings suggests that the participants were generally unaware of the words under this condition.

In our second experiment, we used the multi-trial adaptation of the Mack and Rock (1998) methodology to assess memory for information perceived without awareness following a 0-sec and a 25-sec retention interval. To create the 25-sec retention interval, we inserted seven filler trials between the initial trial when the target word was presented at fixation and the test trial when a stem consisting of the first three letters of the target word was presented. The filler trials were as illustrated in Figure 2, except that neither a word nor a stem was presented. In other words, on each filler trial, the participants were presented the fixation cross, a display with a cross in one quadrant, the mask, and the question, *Which arm of the cross was longer?* Thus there were two trial types in Experiment 2: trials with no delay between presentation of the target word and presentation of the target word's stem (i.e., 0-sec retention interval), and trials with seven filler trials between presentation of the target word and presentation of the target word's stem (i.e., 25-sec retention interval).

A second major change introduced in Experiment 2 was that on each trial other than the filler trials, the participants were asked to assess and to report their subjective awareness of the target word. Immediately after the participants indicated which arm of the cross was longer, they were shown a second question on the monitor screen. The second question asked *How much of the word did you see?* There were three possible replies to this question: (a) *I saw the entire word*, (b) *I saw a few letters of the word*, or (c) *I saw no part of the word.* The participants indicated their decision on each trial by pressing an appropriate key on the keyboard. This assessment of each participant's subjective awareness of each target word was used to classify whether a word was perceived with awareness or perceived without awareness. In this way, it was possible to separate memory for information perceived without awareness from memory for information perceived with awareness.

Before the results were analyzed, all trials were classified as aware or unaware trials based on the participants' assessments of their subjective awareness. Aware trials were those trials on which the participants indicated that they *saw an entire word* (60% of the trials). Unaware trials were those trials on which the participants indicated either that they *saw no part of the word* (15% of the trials) or that they *saw a few letters in the word* (25% of the trials). The justification for considering trials on which the participants' assessment of their subjective awareness was that they perceived *a few letters in the word* as unaware trials was based on two considerations. First, by their own assessments of their awareness, the participants were unaware of the word and were only aware of a few of the letters in the word. Second, and perhaps not surprisingly, given that the participants were unaware of the complete word, the patterns of findings for the two types of unaware trials were virtually identical at both the 0-sec and 25- sec retention intervals.

The results of Experiment 2 are shown in Figure 4. Once again, the dotted line in the figure indicates the baseline level of performance. Looking first at the 0-sec retention interval, it can be seen that for words perceived with awareness, as indicated by the participants' own assessments of their awareness, it was possible for the participants to exclude most of these words from their completions of the word stems. This finding is of course what should occur when words are perceived with awareness. In contrast, for words perceived without awareness, as indicated by the participants' assessments of their awareness, it was much more difficult for the partici-

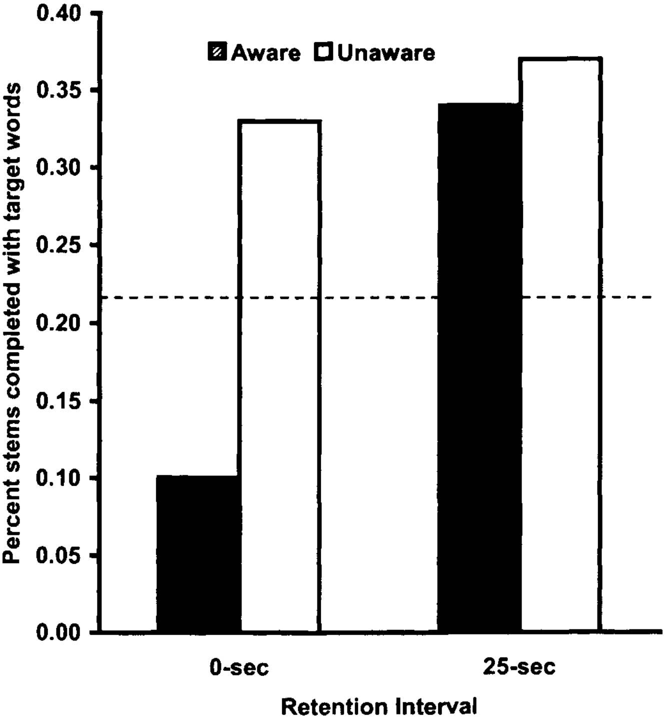

Fig. 4. Experiment 2: Percent of stems completed with target words following the 0-sec and 25-sec retention intervals. Dotted line indicates the baseline level of performance.

pants to exclude these words from their stem completions. As shown in Figure 4, on these trials, the participants used the target words to complete the stems considerably more often than the target words were used on baseline trials. This finding is completely consistent with the idea that these words were perceived without awareness.

The participants' performance at the 25-sec retention interval shows two important findings. First, with regard to the primary question addressed by the experiment, the findings clearly show that there was memory for information perceived without awareness following the 25-sec retention interval. Second, the findings show that the participants' ability to exclude words perceived *with* awareness from their stem completions dissipated rapidly. After only 25 seconds, there was no advantage for excluding words perceived with awareness relative to excluding words perceived without awareness. Thus, following the 25-sec retention interval, performance was influenced in similar ways by memory for words perceived with awareness and by memory for words perceived without awareness.

Given the success of Experiment 2 in demonstrating memory for information perceived without awareness, we were encouraged to assess memory following considerably longer retention intervals. In Experiment 3, there were three retention intervals: 0-min, 16-min, and 32-min. The experiment was similar to Experiment 2 with the following two exceptions. First, no filler trials were included. Rather, all trials were as illustrated in Figure 2 in that, on each trial, both a word and a word stem were presented. The retention intervals were established by varying the number of trials between the presentation of each word and the presentation of that word's corresponding word stem. The second change in Experiment 3 was that the duration of the displays containing the cross and the target word was shortened from 150 ms to 100 ms. This change was instituted to make the proportions of aware and unaware trials, as indicated by the participants reports of their experiences, more equivalent.

The results of Experiment 3 are shown in Figure 5. Again, the dotted line in the figure indicates the baseline level of performance. What is clear from an inspection of Figure 5 is that the overall pattern of findings is very similar to the pattern of findings in Experiment 2. Namely, at the shortest retention interval (i.e., 0 min), participants were generally able to exclude the target words from their stem completions when they were aware of the words at the time they were presented. However, participants were generally unable to exclude the target words when they were unaware of them at the time they were presented. Thus, at the 0-min retention interval, performance on the aware trials was significantly below the baseline level of performance, indicating perception with awareness, whereas on the unaware trials, performance was significantly above the baseline level of performance, indicating perception without awareness. In contrast, at both the 16-min and the 32-min retention intervals, performance on both the aware and unaware trials was significantly above the baseline level of performance. Thus when memory was assessed following the 16-min and 32-min retention intervals, no matter whether the participants indicated that they perceived the words with awareness or without awareness, they were generally unable to exclude the words from their stem completions.

The most important result in Experiment 3 is the finding showing that there is definitely memory following the 32-min retention interval for words perceived without awareness. Thus, Experiment 3 establishes that memory for information perceived without awareness can persist for at least 32 minutes, and suggests the possibility that memory for information perceived without awareness may persist for longer than 32 minutes.

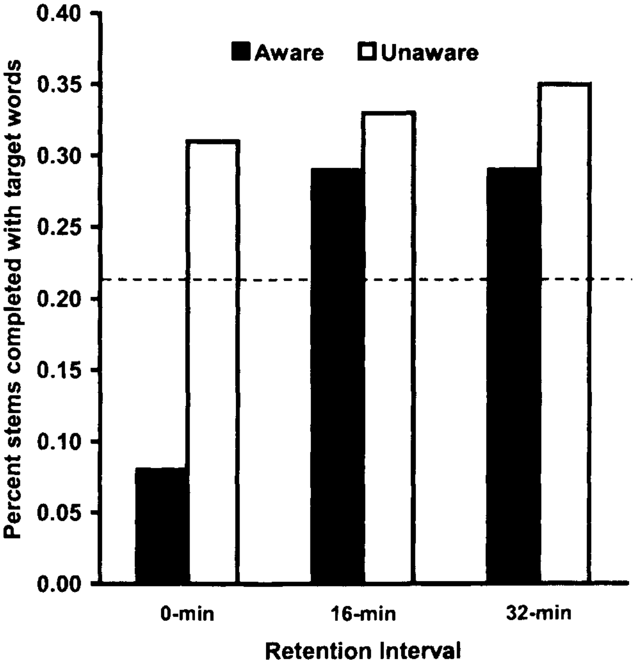

Fig. 5. Experiment 3: Percent of stems completed with target words following the 0-min, 16-min, and 32-min retention intervals. Dotted line indicates the baseline level of performance.

Obviously, what is needed are studies in which memory for information perceived without awareness is assessed following temporal intervals measured in hours, days, or weeks. Studies of memory for events during anaesthesia provide evidence that is particularly relevant. In many of these studies, memory for information presented during general anaesthesia has been assessed over delays measured in hours or days. It is these studies that we turn to next.

Memory for events during anaesthesia

Studies of memory for events during anaesthesia provide a useful avenue for exploring perception without awareness. Even though surgical patients who have been administered general anaesthesia are not supposed to have any post-surgical memory for events during anaesthesia, as early as 1961, there were researchers who claimed to have found evidence of memory for events during anaesthesia. For example, Pearson (1961) reported that positive suggestions during anaesthesia decreased the duration of hospitalization following surgery, and Hutchings (1961) reported that positive suggestions reduced the pain following surgery.

Even more compelling was Levinson's (1965) observation that patients perceived and remembered significant events that occurred during anaesthesia. Levinson staged a mock crisis while surgical patients were under the influence of general anaesthesia. During surgery, 10 anesthetized patients had the following statement recited to them.

"Just a moment! I don't like the patient's colour. Much too blue. Her lips are very blue. I'm going to give a little more oxygen. . . . There, that's better now. You can carry on with the operation." (Levinson, 1965, p. 544)

One month following surgery, Levinson hypnotized the patients to see whether they could remember anything that may have occurred while they were anesthetized. Surprisingly, 4 of the 10 patients were able to provide an almost verbatim account of the statement made during the mock crisis, and another 4 patients had some memory of the message. The results of these early studies certainly suggest that patients may have memory for events during anaesthesia.

Not surprisingly, the findings reported by Pearson (1961), Hutchings (1961), and Levinson (1965) generated considerable interest and motivated additional studies. However, despite a considerable number of studies over the next 40 years, based on a variety of experimental procedures, the findings showed a confusing picture of significant and nonsignificant results. For this reason, Merikle and Daneman (1996) decided to conduct a meta-analysis of all relevant studies investigating memory for specific information during anaesthesia. The advantage of using meta-analytic techniques is that they provide a method for combining and quantifying the results of individual studies so that it is possible to see the general trends across all relevant studies. The primary goal of the meta-analysis was to establish whether the overall pattern of findings provided any support for the view that there is memory for specific information presented during general anaesthesia.

The meta-analysis was based on the results of 29 different studies involving a total of 1492 surgical patients. The results are shown in Figure 6, which shows the average effect sizes summed across direct and indirect measures at three different temporal intervals following surgery. Each effect size is represented by a correlation coefficient (*r*) and reflects the degree of association between the manipulated variable (e.g., old vs. new

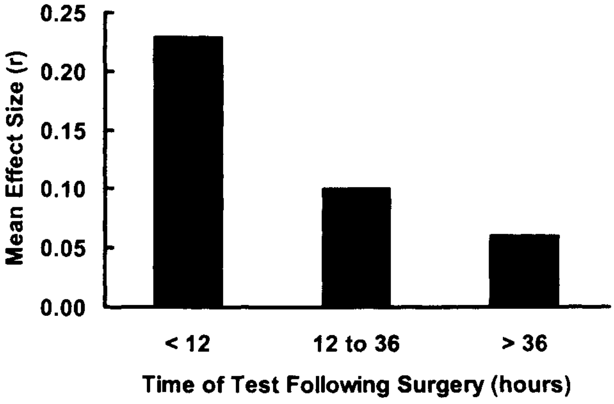

Fig. 6. Mean effect size of memory for information presented during anaesthesia when tested at different temporal intervals following surgery (adapted from Merikle & Daneman, 1996).

words in forced-choice recognition) and performance on the memory test (e.g., forced-choice recognition). The three temporal intervals reflect common research strategies. In 12 studies involving a total of 708 patients, the strategy was to measure memory as soon as possible after the patients regained consciousness (i.e., less than 12 hours following surgery), whereas in 10 studies involving a total of 560 patients, the strategy was to test patients approximately 1 day following surgery (i.e., between 12 and 36 hours following surgery). In the 7 remaining studies involving 224 patients, the memory tests were administered more than 36 hours following surgery, including some instances in which the memory tests were administered more than 2 weeks following surgery.

The pattern of findings shown in Figure 6 is clear: The average effect size decreased systematically as the interval between the end of surgery and administration of the memory test increased. Statistical analyses of the effect sizes indicated that the average effect sizes were statistically significant when memory was tested either less than 12 hours following surgery or between 12 and 36 hours following surgery. However, the very small effect size when memory was tested more than 36 hours following surgery was not significant. Assuming that the patients were truly unaware during surgery/anaesthesia, these findings provide strong support for the conclusion that the impact of information perceived without awareness can last for a considerable period of time.

One question which can be raised regarding the findings reported by Merikle and Daneman (1996) is whether the evidence showing memory for events during anaesthesia may actually reflect perception *with* awareness during brief episodes of consciousness during surgery. It is well known that the depth of anaesthesia during surgery varies. Although anaesthesiologists strive to maintain a level of anaesthesia adequate to ensure that a patient experiences no awareness during surgery, it is always possible that some patients may experience brief periods of awareness, which they subsequently do not and cannot consciously recollect. If critical to-be-remembered materials happened to be presented during the brief periods of awareness that some patients may experience, then the evidence from the meta-analysis showing memory for events during anaesthesia may actually reflect memory following perception *with* awareness rather than memory following perception *without* awareness.

Fortunately, this question has been addressed in a recent study in which the bispectral index (BIS)[1] was used to monitor the depth of anaesthesia during surgery involving trauma patients (Lubke, Kerssens, Phaf, & Sebel, 1999). For trauma patients as a group, there is considerable variation in the depth of anaesthesia. Generally, the more serious the trauma the poorer is the tolerance for anaesthetic agents. As a consequence, less anaesthesia is typically administered to patients with serious trauma than to patients with minor trauma. For this reason, patients with serious trauma are more likely to experience awareness during surgery than patients with minor trauma (Bogetz & Katz, 1984). Thus, as a group, trauma patients are ideal for studying the relation between depth of anaesthesia and subsequent memory for events during anaesthesia.

During anaesthesia, Lubke et al. (1999) presented trauma patients with 16 target words. Each target word was repeated 40 times in succession with a two-sec delay between repetitions, with the total duration of the presentation of each target word being three minutes. Subsequently, the corresponding three-minute recording of the EEG associated with the presentation of each target word was identified; in this way, it was possible to compute the BIS for each of the 16 target words. Consequently, it was possible to establish the depth of anaesthesia for each target word at the time it was presented.

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[1] It has proven difficult to develop an objective indicator of the depth of anaesthesia. To date, monitoring the depth of anaesthesia during surgery has relied primarily on the clinical judgments of anaesthesiologists. The BIS is a promising development. It is based on real-time analysis of the electroencephalogram, and has been found to correlate well with clinical judgments of the depth of anaesthesia.

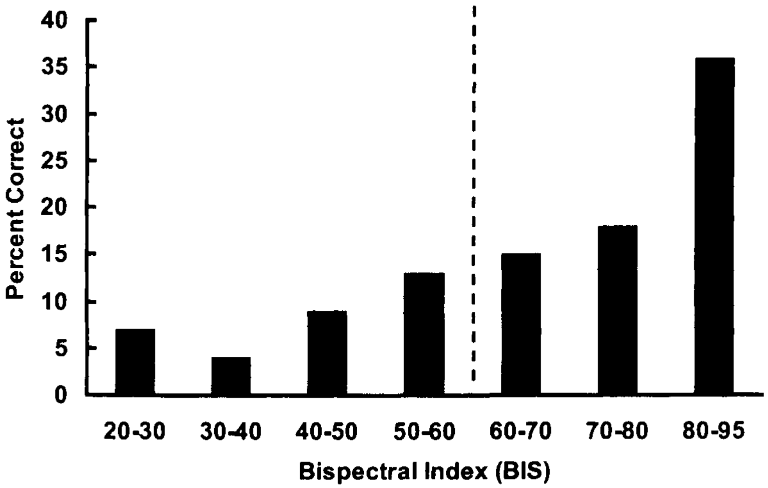

Fig. 7. Mean percent correct stem-completion performance for words presented at different depths of anaesthesia as indicated by the bispectral index. Dotted line indicates level of BIS associated with adequate anaesthesia. (adapted from Lubke et al., 1999).

Lubke and her colleagues (1999) assessed memory for events during anaesthesia by asking the patients to complete word stems with the target words. Figure 7 shows the mean percentage of stems completed with the target words at different depths of anaesthesia, as indicated by the value of BIS. The lower the value of BIS, the greater is the depth of anaesthesia. Two conclusions emerge from a consideration of the findings presented in Figure 7. First, memory for the target words decreased as the BIS decreased; in other words, memory decreased as the depth of anaesthesia increased. Second, there was some memory at all levels of BIS. Critically, the results indicated that there was memory for events during anaesthesia at BIS values between 40 and 60, which are considered by anaesthesiologists to indicate sufficient anaesthesia to prevent all awareness of events during anaesthesia. Thus, the findings reported by Lubke and her colleagues clearly show memory for events during anaesthesia which cannot be attributed to periods of awareness or consciousness during surgery.

Taken together, the results of the meta-analysis reported by Merikle and Daneman (1996) and the results reported by Lubke et al (1999) point to the same conclusion. Namely, when information is presented to patients during general anaesthesia, some patients perceive some of the information without any awareness of perceiving. In addition, the results of the meta-analysis indicate that memory for events during anaesthesia can persist for at least 24 hours. There is also reason to believe that the impact of information perceived without awareness during anaesthesia may extend beyond 24 hours. One limitation of all studies included in the meta-analysis is that the stimulus materials did not have personal relevance for the patients. The typical stimulus materials were single words, and memories for single words, especially relatively high-frequency words, are subject to considerable decay and interference. Thus, it is not particularly surprising that the memories of single words may have lasted only a few hours. If more personally relevant materials had been used in these studies, such as the mock crisis staged by Levinson (1965), then it is possible that the impact of information perceived during anaesthesia might have extended over temporal intervals measured in days or weeks.

Concluding comments

Both our studies and the studies of memory for events during anaesthesia point to the same conclusion: Information perceived without awareness can have an impact for a considerable period of time. Thus, perception without awareness can potentially have important consequences regarding how people consciously experience the world about them (see Merikle et al., 2001).

Our conclusion stands in stark contrast to the conclusion reached by Greenwald and his colleagues (1996). On the basis of the results of a series of semantic-priming experiments, they concluded that the impact of information perceived without awareness lasts for 100 ms or less! There is no doubt about their findings. However, the important question is whether their conclusion generalizes beyond their experiments. We believe that it does not and that the radically different conclusions suggested by their studies and our studies reflects a fundamental difference in the way awareness was assessed.

The success of any study of perception without awareness depends critically on the behavioural measure used to assess awareness. In general, there are two different approaches to the assessment of awareness. One approach is to base the assessment of awareness on the participants' reports of their conscious experiences. Such measures are commonly referred to as subjective measures of awareness (see Reingold & Merikle, 1990). Both our studies and Mack and Rock's (1998) studies are based on subjective measures of awareness whereby participants—through *reports* of their conscious experiences—provide direct assessments of their awareness of critical stimuli. Likewise, if surgical patients report that they were unaware of any events during surgery, anaesthesiologists assume that they were in fact unaware of events during surgery.

In contrast to subjective measures, other approaches to the study of perception without awareness, such as the approach followed by Greenwald and his colleagues (1996), are based on objective measures of awareness. With objective measures, awareness is assessed in terms of *performance* on tasks such as stimulus detection or forced-choice recognition. When stimulus detection or forced-choice recognition approximate a chance level of performance, it is assumed that participants have no awareness whatsoever of critical stimuli.

In general, objective measures of awareness provide misleading estimates of the minimum stimulus conditions needed to perceive a stimulus with awareness. In studies based on objective measures, it is assumed that a failure to discriminate between alternative stimuli indicates that participants are unaware of the characteristics that distinguish the stimuli. This is a relatively non-controversial assumption which is completely consistent with subjective experience. However, a second, unjustifiable assumption, which is not consistent with subjective experience, is often made. The second assumption is that success in discriminating between alternative stimuli *necessarily* indicates awareness of the characteristics that distinguish the stimuli (e.g., Greenwald et al., 1996; Holender, 1986; Kouider & Dupoux, 2004). This second assumption (a) does not necessarily follow from the first assumption, (b) is unsupported by any evidence, and (c) is completely inconsistent with subjective experience. In fact, the only direct evidence regarding whether it is possible to discriminate between alternative stimulus states when there is no awareness of perceiving comes from studies in which awareness has been assessed with subjective measures (e.g., Cheesman & Merikle, 1986; Sidis, 1898). The results of these studies clearly show that participants can discriminate between alternative stimulus states even when they report that they are unaware of the stimuli.

The critical difference between subjective and objective measures of awareness is that objective measures generally provide much more conservative estimates of the minimal stimulus conditions leading to perception with awareness than is provided by subjective measures. Therefore, it is not particularly surprising that studies based on objective measures provide much shorter estimates of the duration of the influence of information perceived without awareness than is provided by studies based on subjective measures. Given that all measures of perception can in principle be influenced both by information perceived with awareness and by information perceived without awareness, the minimal stimulus conditions established using objective measures not only reduce the likelihood of perception with awareness but also reduce the likelihood of perception without awareness. For this reason, subjective measures provide a more accurate measure of the presence or absence of awareness than is provided by objective measures. Although there is sometimes an uneasiness regarding subjective measures, when all things are considered, self-reports of conscious experiences provide both a direct and an accurate indicator of the presence or absence of awareness (see Chalmers, 1996: Merikle, 1992).

Now that it is established that the influence of information perceived without awareness can persist for periods of time measured in hours or even days, it is important to establish more firmly both the duration of the influence of information perceived without awareness and the types of influences that information perceived without awareness can have on other cognitive processes As already mentioned, one limitation of most studies to date is that they have only evaluated the impact of stimulus information which has little personal relevance to the participants (e.g., single words). Given the suggestive evidence that the impact of information perceived without awareness may last for relatively long periods of time if the perceived information has personal relevance (e.g., Levinson,1965), a challenge for the future is to find ways to study the impact of information with high personal relevance when it is perceived without awareness. Another challenge is to establish how information perceived without awareness influences other cognitive processes. It is known that information perceived without awareness can influence both what stimuli are perceived with awareness and how stimuli perceived with awareness are consciously experienced (e.g., Merikle et al., 2001). However, to date there are relatively few studies of the impact of information perceived without awareness. Given that information perceived without awareness can have an impact over considerable periods of time, it is now important to investigate the limits of the impact of information perceived without awareness both on other cognitive processes such as attention, perception, memory, and decision making, and on conscious experience in general.

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The Devil Is in The Detail: A Constructionist Account of Repetition Blindness

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Summary. People have difficulty detecting repetition of a word within rapid lists, although they can report the identities of many of the list words. This repetition blindness effect has been explained through a "type/token" account, which assumes a refractory period for registering second occurrences. In contradiction of that idea, holding the time course constant, we observed release from repetition blindness when critical words were marked while the rapid list was in progress. Also contrary to that account, we observed that subjects can become aware of repetition without becoming aware of what was repeated. We present an account of on-line repetition detection and blindness based instead on construction and attribution.

Key words. Repetition blindness, activation, inhibition, attribution

Introduction

This article contrasts two approaches to understanding the mechanisms by which people come to perceive and have conceptual knowledge of stimuli around them, and to later remember the occurrence of those stimuli. One is based on the principles of activation and inhibition; the other on the principles of construction and attribution. These hypothetical mechanisms are rooted in completely different assumptions about the global architecture of memory, the form of representation of knowledge about general concepts and particular events, and the means by which the experience of a stimulus in some context leads to a conscious understanding of and subjective reaction to that stimulus. We use the phenomenon of "repetition blindness" to illustrate these different assumptions and as a test case to investigate their relative explanatory utility.

Activation and Inhibition versus Construction and Attribution

The idea of activation and inhibition as mental mechanisms can be traced back to Descartes' (1641/1978) discovery of the spinally mediated reflex and the British Associationists' subsequent conception of the acquired mental reflex. Accounts using these assumptions posit a direct connection between the stimulus, its representation in memory, perception and awareness of the stimulus while it is physically present, and later remembering of it. These constructs have been used to explain a wide variety of perceptual and remembering phenomena, including semantic priming (e.g., Collins & Loftus, 1975), negative priming (e.g., Tipper, 1985), the Stroop effect (Logan, 1980), attentional blink (Chun & Potter, 1995), repetition blindness (Kanwisher, 1987), the inhibition of return effect (Klein, 1988), retrieval-induced forgetting (Anderson, Bjork, & Bjork, 1994) and directed forgetting (Bjork, 1989).

In contrast, the ideas of construction and attribution have their philosophical roots in the writings of Thomas Hobbes. According to Hobbes (1651/1967), sense-impressions result from contact with objects in the world, but are not isomorphic with those objects. Instead, the interaction between memory and the stimulus creates in mind an Appearance, a psychological semblance that is not a representation of the object of perception, but instead of the perceiver's reaction to it. Psychological investigation of construction and attribution can be traced back to Helmholtz and Bartlett. Helmholtz (1910/1962) realized that 3-dimensional perception could not result from vision per se, because the retina is a flat surface, unable to represent the third dimension. Instead, he argued that the perception of depth must result from a constructive mental process, in which depth is inferred from "painter's cues" such as interposition, perspective, relative retinal size, nearness to the horizon, fuzziness and so on. Similarly, Bartlett (1932) realized that remembering is not regurgitation of earlier experiences, but instead an attempt to make sense of what comes to mind on a later occasion. He did not doubt that the coming-to-mind of ideas about the past was driven by records of those earlier experiences, but argued that the representation formed in the moment of experience was a record of how the person *understood* the event, given their background experiences and the context within which the event occurred; and that the later act of remembering was even further distanced from the reality of the event, consisting of an inference about what *must have been*, given what can be generated about the past in the current moment.

The idea that memory works inferentially in forming perceptions in the moment of experience and later in reconstructing remembrances was examined rigorously by later investigators such as Jacoby (e.g., Jacoby &

Dallas 1981; Jacoby & Whitehouse, 1989), Loftus (e.g., Loftus & Palmer, 1974; Loftus, Miller, & Burns, 1978); Bransford and Franks (e.g., 1971) and Johnson (e.g., Johnson, Hashtroudi, & Lindsay, 1993; Johnson & Raye, 1981). There is now an enormous literature demonstrating that feelings of familiarity, truth, understanding, duration and clarity result from attributions about the quality of the perceiver's experience of a stimulus (rather than properties of the stimulus itself) or the quality of the residue of that experience on a subsequent occasion (e.g., Begg & Armour, 1991; Higham & Vokey, 2000; Jacoby, Woloshyn, & Kelley, 1989; Lindsay & Kelley, 1996; Mandler, Nakamura, & van Zandt, 1987; Masson & MacLeod, 1996; Rajaram & Roediger, 1997; Seamon, Luo, & Schwartz, 2002; Whittlesea & Leboe, 2003; Witherspoon & Allan, 1985). All of this work demonstrates that memory does not work by simple registration of stimuli and later reduplication of the features of the event, but instead by construction in the moment and reconstruction on a later occasion.

Repetition Blindness

The phenomenon of repetition blindness, initially observed by Kanwisher (1987), consists of the observation that when short lists of unrelated words are presented in rapid serial visual presentation (RSVP) lists at around 150 ms per word or faster, with a lag of only one or two intervening words, people have much more difficulty reporting the occurrence of repetition of a word than they do in reporting that the word occurred at all. It is something of a paradox, in the sense that the usual consequence of repetition is to enhance processing (the well-documented repetition priming effect: e.g., Scarborough, Cortese, & Scarborough, 1977). Adding to the complexity of the effect, double presentation of a word within the list can increase the probability of reporting that word as having occurred at least once within the list, without allowing the person to know that it occurred twice.

Kanwisher (1987; 1991; Kanwisher & Potter, 1990; Park & Kanwisher, 1994) argued that repetition blindness results from inhibited encoding. She appealed to the idea that memory has two basic kinds of representation, *types* and *tokens* (cf. Anderson & Bower, 1973; Simon & Feigenbaum, 1964). Types are thought to be representations of generic concepts; they are nodes within a hypothetical semantic network. Activation of a type grants the person access to the meaning associated with the stimulus. It also has a secondary effect, of creating a token that marks the occurrence of the stimulus having the meaning given by the type. Thus, in reporting a list of words that has just been presented, a person is assumed to scan memory for types having the appropriate token attached to them; on finding such types, the person can report that a certain stimulus actually occurred within that context, using the token as evidence of occurrence of that stimulus and the type to report its identity. A word will be reported as being repeated only if the scan reveals two tokens. By this account, the phenomenon of repetition blindness occurs because tokenization has a refractory period. A type that has just been activated can be effectively reactivated immediately afterward, which is the source of the heightened likelihood of reporting the identity of a repeated word as having occurred within the list. However, a type cannot be immediately re-tokenized, so that words that are repeated too soon after their earlier occurrence cannot be marked again as having occurred. The second occurrence is thus not registered in memory as a separate event, causing the person to report the word as having occurred only once.

There have been a number of other explanations of the repetition blindness effect, suggesting that it occurs in whole or part through retrieval failure (Armstrong & Mewhort, 1995; Fagot & Pashler, 1995), failure of reconstruction (Masson, Caldwell, & Whittlesea, 2000; Whittlesea & Podrouzek, 1995; Whittlesea & Wai, 1997), or failure of on-line perceptual integration processes (e.g., Johnston, Hochhaus, & Ruthruff, 2002). Repetition blindness has also been investigated using repeated pictures (Kanwisher, Yin, & Wojciulik, 1999), or individual alphanumeric characters (Bavelier & Potter, 1992), or pairs of orthographically similar, but not identical, words (Bavelier, Prasada, & Segui, 1994; Chialant & Caramazza, 1997; Morris & Harris, 2002). While acknowledging those approaches, we will focus on repetition blindness occurring in the context of exact repetition of words within rapid lists; we will also attempt to examine experimentally only processes which occur during the presentation of the RSVP list, rather than retrieval or reconstructive processes occurring after the list, in the act of reporting it. Further, we will concentrate on the type/token account, to contrast the utility of accounts based on assumptions of activation and inhibition versus construction and attribution.

The experiments in this chapter were motivated by the SCAPE framework of memory (e.g., Whittlesea, 1997, 2002a, 2002b, 2003; Whittlesea & Leboe, 2000). By that account, people do not simply *register* stimuli (as suggested by the activation assumption of the type/token account): instead, they *construct* them, imposing organization and meaning on those aspects of the physical world that are salient and that they have the capacity to process, based on the similarity of those aspects to the contents of previous processing experiences. According to the SCAPE framework, knowledge of repetition within the current environment must be constructed like any other property. By that account, repetition can be detected in either of two ways: Both must fail for the person to exhibit repetition blindness. One is to encode each item as it is presented, along with whatever aspects of its context one can, and then after the list is presented to attempt to remember all of the items with their contexts. In this act of post-list reconstruction, remembering a word as occurring in two distinct contexts permits the person to decide that they saw it twice. The problem with this procedure as a means of repetition detection is that it critically depends on recalling both contexts; recalling just one only assures the person that they saw the word at least once. (This problem is identical to that of remembering repeated events in the long-term. Remembering that one ate popcorn *at the beach* does not enable one to state that one ate popcorn twice in the last week, however forcefully that idea comes to mind. Only remembering also that one ate popcorn *in the park* permits that decision.) The further problem is that items presented in rapid lists are not well-integrated with their contexts. In consequence, people are much more able to report the identities of the words in a rapid list than they are to remember their individuating contexts, resulting in failure of reconstruction of repetition after the list. This idea provides an alternate explanation of the common observation that repetition blindness is most pronounced at a lag of one (at which the two occurrences actually share the context of the intervening item) and reduces with increasing lag (as the contexts become more distinct). This reconstructive way of detecting repetition (and the reasons why it fails in rapid list presentation) has been extensively documented (cf. Masson, Caldwell, & Whittlesea, 2000; Whittlesea, Dorken, & Podrouzek, 1995; Whittlesea & Podrouzek, 1995; Whittlesea & Wai, 1997).[1]

The other way to detect repetition, which is examined in this chapter, is through on-line construction. Under the assumptions of the SCAPE framework, in encountering each successive stimulus in a list, the person has a variety of options about how to construct an understanding of the stimulus (the principle of encoding variability: e.g., Light & Carter-Sobell, 1970). Although some operations are performed fairly automatically on some familiar types of stimulus, no type of information is simply registered. For example, accessing the identity of a common word, although extremely well-practiced, is not obligate even in slow presentations (Stolz & Besner, 1999). Instead, to become aware of some property of the stimulus, the person must actually perform appropriate operations on it, which requires time and processing resources. To detect repetition on-line, the

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[1] A related way of detecting repetition after the list is to experience a heightened sense of familiarity for the repeated word. That basis of repetition detection was investigated by Whittlesea and Podrouzek (1995).

person must compare each successive item, as it is shown during the list presentation, to memorial records of earlier items. Finding a match enables the person to become aware *at the moment of repetition* that repetition has occurred. That procedure works well with slow lists, when the person has time both to identify the word and also to perform the comparison.[2] Fast presentation reduces the ability to perform those activities. Instead, under those circumstances, each occurrence of a repeated word is likely to be processed ineffectively or incompletely, and independent of the processing of the other occurrence of the same stimulus (Whittlesea, Dorken, & Podrouzek, 1995).

The problem is exacerbated by the fact that, under the usual procedures in which repetition blindness is observed, the repeated stimulus is embedded within a list of non-repeating stimuli. Although this detail is not usually mentioned as part of the source of the effect, it is critical for producing it: If instead a word is presented twice, with one other word intervening between its occurrences, at the standard presentation rate, and with no pre- or post-masking, the repetition is quite obvious. Presenting the critical stimulus within a larger list introduces an extra problem for the subject, namely uncertainty about which stimulus may repeat. In consequence, the person must examine and test every word for repetition. The result is that the perceptual system is often already engaged in attempting to process one stimulus when another (the critical stimulus) is presented. The uncertainty about which stimulus may repeat thus limits the effectiveness of constructing a perception of any stimulus. By this logic, the subject's problem is not selectively in dealing with repetition (as suggested by the type/token account); instead, it is caused in part by the need to process the *non-repeated* items. That is, we suggest that repetition blindness is not a phenomenon caused exclusively by repetition, but instead in part by the demand to detect repetition under uncertainty about what may repeat.

To summarize, the type/token account suggests that repetition blindness results from inhibited encoding of repeated occurrences, caused by a refractory period for re-tokenization of a type. In contrast, the SCAPE framework denies the type/token dichotomy. Instead, it suggests that the phenomenon results from ineffective on-line construction of a perception of repetition, caused by the speed of presentation and the need to test non-repeated stimuli for repetition; and also ineffective reconstruction of the separate experiences of the two occurrences after the list, caused by the

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[2] However, it is by no means an automatic process, even with slow presentations: for example, the reader probably cannot report how many times the word "the" occurred in the last sentence.

lack of distinctiveness of the representations of repeated stimuli in rapid lists.

Experiment 1: On-Line Exogenous Cues

Our first experiment presented 6-word lists, at 120 ms per word. A cue word was presented after each list; the subjects were asked if that word had occurred zero, one, or two times within the list. In this study, the cue word was always presented either once or twice in each list. The crux of this study was that all of the words were presented in black in two conditions, whereas in the other two conditions two words were presented in red. In one of these conditions, both of these red words were the same as the cue word presented after the list (which was presented in black, like the rest of the list); in the other, the second red word was the same as the cue word, but the first red word was a different word. The logic of this design was that the red presentations might simplify the subjects' task, by enabling them to focus their processing selectively on the words that were candidates for repetition. If repetition blindness results from a refractory period for establishing tokens for the same type, this procedure could not facilitate repetition detection, because the time-course of presentation was the same in all conditions. In contrast, if repetition blindness is caused by the extra load of having to interrogate each word in the list, it should be substantially reduced by the red presentations.

Method

All subjects in these studies were students at Simon Fraser University, participating for course credit. Twenty students participated in Experiment 1.

All lists of words in this and succeeding experiments consisted of 6 words. The non-critical words (used to fill out the background of the lists) varied in length from 4 to 7 letters; they were taken from lists published by Stadler, Roediger, and McDermott (1999). However, the target stimuli (stimuli that the subject was asked to report on) were all 6 letters in length (e.g., RECENT, EXPORT, INTENT). These target words were randomly assigned to lists and to conditions, the assignment being re-randomized for each subject. There was thus no systematic connection between the target words (in linguistic frequency, meaningfulness, or any other characteristic) and the conditions in which they were displayed, or with other words within the list. This procedure was followed in all subsequent studies.

In Experiment 1, one of the 6-letter words was presented after each list, and, depending on the condition, either once or twice within the list. There were 4 conditions, each of 18 trials, all trials being presented in an order freshly randomized for each subject. In the first condition, all words were presented in black on a white background. One of the 6-letter words was presented in either location 2 or 3 of the 6-word list; a different 6-letter word was presented two locations later (lag one), either at location 4 or 5. This placement was randomized, subject to the constraint that the two kinds of placement occurred with equal frequency across the trials of the condition. The placement of the words at those locations ensured that they were always pre- and post-masked by at least one other word. In addition, each list was pre- and post-masked by a row of 12 symbols (e.g., #$% etc.), presented for 250 ms. Each trial began with a READY prompt. On a keypress by the subject, the screen blanked for 250 ms. Following that, each word of a list was presented centred on the screen, for 120 ms, followed immediately by the next word. After the list, the subject was shown the second of the 6-letter words, as a recognition cue, with the instruction "Did this word occur zero, one, or two times?" The subjects responded by striking one of three buttons.

The second condition was identical, except that the same 6-letter word was presented in both locations 2 and 4 or 3 and 5 (repetition condition). The third and fourth conditions were identical to the first and second, except that the critical 6-letter words were presented in red within the list, the other words (and the cue word following the list) being shown in black. There was no warning, from trial to trial, about whether the next list would be all black or contain red words.

Results and Discussion

As shown in Table 1, when the whole list was presented in black, the subjects detected the occurrence of once-presented words on (.60 + .01 =) 61% of trials. Under the assumption that recognition detection consists simply of independent detection of both occurrences of a repeated word, one would expect the subjects to report repetition on ($.61^2=$) 37% of trials. However, as shown in the second row of the table, they only reported repetition on 7% of trials. They were thus substantially blind to the repetition when all words were presented in black.

Showing a once-presented word in red (with another word in red two locations earlier) increased claims of occurrence (claims that that word had occurred at least once: .65 + .05 = .70) by 10% relative to presenting it in black, $F(1,19) = 6.84$, $MSE = .01$, $p = .017$, $\eta^2 = .26$. Presenting a word

Table 1. Experiment 1: Cue word presented after list; three response categories

	Claimed presentation frequency		
	Zero	One	Two
All black, no repetition	.39	.60	.01
All black, repetition	.13	.80	.07
Two red, no repetition	.30	.65	.05
Two red, repetition	.05	.53	.42

twice in red had a much more dramatic result, increasing claimed repetition to 42%, $F(1,19) = 42.79$, $MSE = .03$, $p < .001$, $\eta^2 = .69$. That observed value is not much different than what would be predicted by independent encoding of the two occurrences, which would be ($.70^2 =$) 49%, and in fact was not reliably different from that prediction, $F(1,19) = 1.56$, $MSE = .03, p < .226$, $\eta^2 = .08$. Presenting the repeated item in red thus apparently caused release from repetition blindness.

That release is predictable from the assumptions of the SCAPE framework: Cueing the subjects to attend selectively to the red words enabled them to avoid wasting resources on non-target words, thus more effectively dealing with repetitions. It is less clear that the type-token account can accommodate such results. The time-course of red presentations was identical to that of black presentations. Under those circumstances, it would seem that that account can be held to its refractory period premise: It must predict that tokenization of a second occurrence occurring at a lag of one at such rates of presentation should be inhibited, causing equal repetition blindness for red and black presentations.

Experiment 2: Control Conditions

As indicated earlier, subjects in Experiment 1 were asked whether the cue word (presented after the list) had been presented zero, one, or two times within the list. Table 1 demonstrates that the subjects often used the "zero" response category. However, the cue word was always presented at least once within the list. Inclusion of the deceptive "zero" response category might therefore be thought to have biased the subjects' processing in some way that renders these results unuseful. In Experiment 2A, we changed the subjects' decision to a simple decision of whether the cue word had been shown repeatedly or only once within the list. In Experiment 2B, we eliminated the provision of a cue word after the list; subjects were simply asked whether any word within the list was repeated.

Table 2. Experiment 2A: Cue word presented after list; forced-choice repetition decision

	Claimed repetition
All black, no repetition	.10
All black, repetition	.19
Two red, no repetition	.17
Two red, repetition	.51

Method

Nineteen students participated in Experiment 2A and twenty-one in Experiment 2B. These studies were identical to Experiment 1, except in the ways just described.

Results and Discussion

In both studies, the subjects were substantially blind to the repetition when all stimuli were black, the difference in claims of repetition on repeated versus non-repeated trials being only 9% and 6% in Experiments 2A and 2B, respectively (Tables 2 and 3). Presenting two words in red slightly increased false claims of repetition (by 7% and 8%), that effect being reliable in Experiment 2A ($F(1,18) = 6.87$, $MSE = .01$, $p = .017$, $\eta^2 = .30$) but not in Experiment 2B ($F(1,20) = 2.03$, $MSE = .02$, $p = .169$, $\eta^2 = .10$). In contrast, accurate claims of repetition for words presented in red increased by 32% and 36% compared to all-black trials, $F(1,18) = 21.37$, $MSE = .04$, $p < .001$, $\eta^2 = .54$ and $F(1,20) = 27.49$, $MSE = .04$, $p < .001$, $\eta^2 = .60$. The pattern of data in both studies was very similar to that in Experiment 1, indicating that presenting a cue word after the list and the inclusion of a zero response category were not responsible for the effect observed in Experiment 1.

Together, the three studies demonstrate that reducing the requirement to process non-repeated items permits the subjects to detect the occurrence of repetition with much greater accuracy. That suggests that at least part of the locus of the repetition blindness effect is in the processing of non-repeated items, not repeated items. The only way that the type-token account can explain such results is to assume that selectively attracting attention to the two occurrences of repeated words by making them red somehow defeated the refractory principle, leading to tokenization of both

Table 3. Experiment 2B: Cue word not presented after list; forced-choice repetition decision

	Claimed repetition
All black, no repetition	.07
All black, repetition	.13
Two red, no repetition	.15
Two red, repetition	.49

occurrences. It is not clear how that could occur: By definition, a refractory period is a period during which a unit cannot be re-activated.

Experiment 3: Endogenously-Controlled Selective Processing

In Experiments 1 and 2, we reduced repetition blindness by attracting attention to the critical occurrences of words within the RSVP lists. In Experiments 3A and 3B, we instead attempted to reduce the processing of non-target stimuli without marking the target stimuli in any special way. To do that, we used a procedure similar to Experiment 1, but without any red presentations. Instead of that manipulation, in two conditions we replaced the non-target list words with nonwords that were created by random concatenation of letters. Because these nonwords were mixtures of consonants and vowels, they look much like words when presented at 120 ms each. That is, there is nothing in the physical signal to mark these items out as stimuli not to be processed, nor is there anything exogenous in this procedure to draw attention selectively to target words. However, although they possess word-like graphemic properties, nonwords constructed in this way have poor orthographic coherence. In consequence, they do not support the variety of constructional procedures (e.g., orthographic, phonological, semantic) that people impose on natural words. That is, we suspected that our subjects simply could not do much when they encountered these nonwords. If our hypothesis that repetition blindness is in part due to processing non-target items is correct, then failure to be able to do much with those items might free the person to perform more extensive processing on repeated targets. In that case, we should observe superior repetition detection when the target items were presented in lists of nonwords.

Method

Twenty students participated in Experiment 3A and 22 in Experiment 3B. Two conditions of this study were identical to the all-black conditions of Experiment 1, including the presentation of two 6-letter target words (either occurrences of the same word or different words) at list locations 2 and 4 or 3 and 5 and the provision of a cue word after the list. The other two conditions were similar, except that all words in the list other than the two critical ones were replaced by nonwords. These items were at random between 4 and 7 letters in length, and were constructed by random selection of any letters of the alphabet, subject to the restriction that vowels were selected three times as often as consonants. No restriction was placed on repetition or location of letters. In Experiment 3A, the critical (natural) words were presented at the standard locations (2 and 4 or 3 and 5 of the 6-word list), with equal frequency; half of these trials presented the same word twice, the remainder showed two different words. In the latter case, the cue word presented after the list for the frequency judgment was the second target word. Experiment 3B contained the same four conditions (repetition / nonrepetition crossed with natural word/nonword backgrounds); the only difference was that in the non-repetition condition on non-word trials, only a single natural word was presented, in location 4 or 5, all other items being nonwords.

Results and Discussion

As shown in Table 4, in the "standard" conditions of Experiment 3A, in which critical words were presented either once or twice in the context of a list of natural words, the subjects again showed considerable blindness to repetition, reporting a word presented once as having been shown once on 56% of trials but reporting a word presented twice as having been shown twice on only 9% of trials. However, the critical result was that the subjects were able to detect repetition about 6% more often when the remainder of the lists was nonwords rather than words (comparing rows 2 and 4), $F(1, 19) = 4.39$, $MSE = .01$, $p = .050$, $\eta^2 = .19$. Although much smaller than the effects of turning repetitions red, we believe that this effect supports the same conclusion, that reducing the processing of non-target items increases the subjects' ability to detect repetition of target items. Unlike the earlier studies, that reduction in processing was achieved not by an exogenous physical cue, but instead by simply making it more difficult to perform any effective processing on non-target stimuli.

Table 4. Experiment 3A: Word and non-word background

	Claimed presentation frequency		
	Zero	One	Two
Words in list, no repetition	.43	.56	.01
Words in list, repetition	.11	.80	.09
Non-words in list, no repetition	.56	.43	.01
Non-words in list, repetition	.13	.72	.15

There was one curiosity in the data: When a target word had been presented once (preceded by a different natural word) in non-word contexts, it was judged to be presented once less often that the same type of presentation in an all-word context, by about 13% (rows 1 and 3 of the table), $F(1, 19) = 6.02$, $MSE = .03$, $p = .024$, $\eta^2 = .24$. That is opposite to the effect that occurred with presenting those words in red within word contexts. In trying to understand this effect, we focused on the fact that in non-repetition conditions the word cued after the list was always the second of two 6-letter target words presented within the list. We therefore suspected that it might be due to an attentional blink (a non-specific interference effect occurring when an earlier stimulus attracts attention and prevents effective processing of a second stimulus, presented shortly after: e.g., Potter, Staub, & O'Connor, 2002; Raymond, Shapiro, & Arnell, 1992; Shapiro, Raymond, & Arnell, 1994). Specifically, we suspected that the nonword context enabled the subjects to process the first natural word more effectively than in an all-word context, and that that augmented processing prevented effective processing of the word presented two locations downstream. Although attentional blink was not the subject of our investigation, we conducted Experiment 3B to test this idea. In that study, when a word was not shown repeatedly, only a single natural word was presented within the list of nonwords.

As shown in Table 5, under those circumstances, the effect for non-repeated words reversed (see rows 1 and 3 of the table): Words presented once were judged to have been presented once about 15% more often when presented in a list of nonwords than in a list of words, $F(1, 21) = 12.28$, $MSE = .02$, $p = .002$, $\eta^2 = .37$. That supports the idea that the effect seen on those words in Experiment 3A was an attentional blink. It also suggests that the effect of nonword contexts on report of repetition observed in the last study may actually underrate the effect of that manipulation, if attentional blink was also operating on those trials in opposition to that factor. More important, we observed once again that repetition was detected more easily (by about 8%) when repeated words were embedded in nonwords rather than words (rows 2 and 4 of the table), $F(1, 21) = 5.09$, $MSE = .01$,

Table 5. Experiment 3B: Manipulation check for attentional blink

	Claimed presentation frequency		
	Zero	One	Two
Words in list, no repetition	.54	.44	.02
Words in list, repetition	.16	.76	.08
Non-words in list, no repetition	.40	.59	.01
Non-words in list, repetition	.21	.63	.16

$p = .035$, $\eta^2 = .20$. (Again, this observation may underrate the true effect of nonword contexts in facilitating repetition detection, owing to a putative attentional blink on those trials.) That replication again suggests that repetition blindness does not result from repetition at short lags per se, but instead at least in part from the demands on the subject to process the non-repeated stimuli in the list. Although presenting nonwords was not as effective in causing subjects to focus their processing selectively on target items as was presenting those items in red, the fact that reducing processing of non-target items had any effect on detection of repetition of target items at least complicates the type/token account. That account must now explain how reducing the processing of the context items leads to an increase in the likelihood of tokenizing the second occurrence of a repeated word. The idea that this procedure frees attentional or processing resources, which is basic to the construction account, does not seem relevant to the type/token explanation of this effect, because by that account inhibition of tokenization is time-locked, not attention-limited.

Experiment 4: Activation and Access to Identity

We now turn from examination of the inhibition assumptions of the type/token account to an investigation of its assumptions about activation and conscious access to the meanings of words. Under the assumptions of that account, tokenization is consequent to activation of the type representation; and activation of the type gives the person access to the identity of the word. By that account, on those trials on which the subjects became aware of repetition, the type must have been activated twice. That is, by that account, people gain access to the knowledge of repetition by repeatedly gaining access to the identity of the repeated word. In consequence, if that account is correct, when people become aware that a word is repeated, they must also know what word is repeated. Experiment 4 was conducted to test that idea.

Experiments 1 and 2 seem to support this assumption of the type/token account. In Experiments 1 and 2A, the subjects were required to make a claim about the repetition status of a specific word, cued after the list; in Experiment 2B, they were only asked whether or not repetition occurred within the list, without having to think about the identity of the word that was repeated. That difference in procedure made no apparent difference to their success in reporting repetition (compare Tables 2 and 3). In turn, that seems to suggest that whenever the subjects knew a word was repeated, they also knew what word was repeated.

However, in Experiments 1 and 2A, the word presented after the list had perfect cue validity for presentations within the list: That is, *if* a word was presented repeatedly, it was always the word presented after the list as a cue. That meant that one of two things could underlie the high reports of repetition when words were presented in red in Experiments 1 and 2. One, suggested by the type/token account, is that, on encountering the two red occurrences, the subjects gained access to the identity of the repeated words and knew, prior to the presentation of the cue after the list, what word was repeated. The other, suggested by the SCAPE framework, is that the two red presentations allowed them to construct sufficiently extensive orthographic representations to detect that the second red item was the same as the first, but not always sufficient to know what the word was. In that case, they would agree that the target word was presented repeatedly because they were aware that *something* repeated; on the understanding that if anything was repeated it was the word presented later as a cue, they reported that that word was repeated. These possibilities cannot be distinguished using the data of Experiments 1 and 2.

To test these ideas, we conducted a study similar to Experiment 1, but in which the word presented after the list had only 50% cue validity. In this study, two words were presented in red within the RSVP list in all conditions. In two conditions, the two words in red within a list were different; in the other two, they were occurrences of the same word (i.e., repeated presentation). Crossed with that manipulation, the cue word presented after the list was either the same as a word presented in red in the list (the same as both, in the case of repetition) or the cue word was a different word, that was presented nowhere in the list. In all conditions, as in Experiment 1, the subjects were asked whether the cue word presented after the list had been presented within the list zero, one, or two times. In this procedure, unlike Experiment 1, knowing that something was repeated without knowing the identity of the repeated word would not permit the subjects to answer the question asked: To know that a specific word had been presented twice within the list, one would have to be able to extract the identity of the word (as well as the fact of repetition) from the rapid presentations. Thus, if presenting the word repeatedly in red gives the subjects access to its meaning, independent of presenting it later as a cue word, then the rate of claiming a cue word to be repeated when it actually was should be identical in this study to the rate of doing so in the parallel condition in the earlier study. In contrast, if the subjects in Experiment 1 often gained access to the identity of a repeated word only when it was presented after the list, then the rate of claiming a cue word to be repeated when it was should be substantially less in this procedure than in the previous study.

Method

Twenty students participated in this study. All of the RSVP lists in this study contained two words presented in red, with equal frequency at locations 2 and 4 or 3 and 5, the remainder being shown in black. On half of the trials, the red words were the same word, but different on the other half. On half of the trials presenting a repetition and half of the trials showing two different words in red, the cue word presented after the list was yet another 6-letter word that was not presented anywhere in the list. That is, unlike Experiment 1, on half of the trials, the cue word actually was not presented within the list, so that the "zero" category was now a valid option. On the remaining trials, the cue word was the same as the repeated word or the second of the red non-repeated words in the list. Otherwise, this study was identical to Experiment 1.

Results and Discussion

As shown in Table 6, the rate of claiming that the cue word (presented after the list) had occurred in the list when it had not was only 17%, whether some other word was presented repeatedly in red within the list or not (first two rows of Table 6). The subjects thus appeared quite able to distinguish between the cue word and the word(s) highlighted in red within the list. That could be accomplished either if they had fully identified the semantic features of the RSVP words or only encoded enough of their orthographic form to recognize that the form of the cue word was different. Cue validity was not an issue in these conditions; so long as the target word felt unfamiliar, they could reject it without a further decision about its repetition status. In the third condition, in which the target word was presented within the list at one of the two highlighted positions, the subjects claimed it to be present once on 63% of trials, otherwise primarily claiming it was

Table 6. Experiment 4: Cue word presented after list, but with .5 cue validity

	Claimed presentation frequency		
	Zero	One	Two
Cue word not in list, no repetition	.82	.17	.01
Cue word not in list, repetition	.82	.17	.01
Cue word in list, no repetition	.34	.63	.03
Cue word in list, repetition	.12	.68	.20

not present. Their performance in this condition was nearly identical to that of subjects in the comparable condition of Experiment 1, despite the difference in cue validity (as can be seen by comparing row 3 of Tables 1 and 6). That seems to suggest that the change in cue validity made no difference to them and that therefore they must know the identity of the words presented in the highlighted positions, independent of the presentation of that word in clear after the list.

However, there is another possible interpretation that can be placed on this observation. The very high rate at which the subjects rejected the target word in the first two conditions suggests that it felt distinctly unfamiliar, perhaps because its orthography was quite different from anything presented within the list, particularly the two words in red. When, in the third condition, the subjects (correctly) felt that there was no repetition, and therefore felt that they had seen two different words in red, and also did not feel the last word to be wholly unfamiliar, they felt quite safe in claiming that the word presented afterward was one of the two words presented within the list. They could get away with that claim because they were not asked which red occurrence, first or second, was the same as the word presented afterward. That is, so long as the cue word did not feel unfamiliar, in this condition these subjects were in effect operating under perfect cue validity, being assured that the target word would be one of the two presented red words, if it had been presented at all. The lack of difference between the experiments in this condition was therefore not very informative about the major question.

In contrast, in the fourth condition of the present study, the subjects faced a tougher decision. If they felt that there was repetition within the list, and the word afterward did not feel distinctly unfamiliar in form, they then had to decide whether it was the same as the word presented repeatedly within the list. That is, this is the first condition in which the .5 cue validity could give the subjects a problem. And it clearly did. As shown in Table 6 (bottom row), in this condition the rate of reporting that the cue word had occurred twice when that word had been shown twice in red within the list was only 20%. That is 22% less often than in the comparable condition of Experiment 1, $F(1, 38) = 9.18$, $MSE = .05$, $p = .004$, $\eta^2 = .20$. That is, although the double red presentation made it quite easy for the subjects to report seeing repetition of the cue word in Experiment 1, subjects in Experiment 4 were less than half as likely to claim that the cue word had been repeated, although the presentation conditions were identical in the two experiments (word that would later be presented as target shown twice in red within list, same locations and temporal parameters). The only difference was that subjects in Experiment 1 operated under perfect cue validity, so that they did not have to know the identity of the repeated word, or even have a well-formed orthographic representation of it, to claim that that word (when presented after the list) had been presented repeatedly. In contrast, subjects in Experiment 4, operating under .5 cue validity, would need one or the other of those to know if the word that they had experienced repeatedly within the list was actually the word presented after the list. The large difference in reporting repetition in the two studies thus suggests that in Experiment 1, the subjects often correctly reported the target word as having been repeated, without knowing the identity of the repeated word until it was shown after the list. In turn, that means that the subjects in Experiment 1 often knew that there was repetition without knowing what was repeated, in violation of the assumptions of the type-token account.

This evidence and argument may seem to conflict with evidence that has been observed in many studies, that subjects can often report the identities of several words presented in RSVP lists, although they have difficulty reporting whether there was a repetition. That evidence has been taken to mean that the subjects acquired knowledge of those identities on-line, while the RSVP list was in progress, consistent with the assumption of the type-token account that people acquire knowledge of the meaning of stimuli through activation of their corresponding types. However, that evidence does not actually indicate whether the subjects achieved knowledge of the identities of the stimuli that they later reported at the moment they encountered the stimuli during the list. An alternate possibility, which is consistent with the current evidence, is that on-line the subjects may sometimes only acquire an impoverished or incomplete impression of the orthography of the successive words. After the list (or while the list is still in progress but after the critical word has disappeared), they review these fragmentary records, reconstructing their orthography, guided by the mass of their prior experiences of encountering the structures of particular natural words, and imposing on them an identity that seems most plausible, given the reconstructed orthography (cf. Masson, Caldwell, & Whittlesea, 2000, and Whittlesea, Dorken, & Podrouzek, 1995, for evidence of such post-list disambiguation).

In fact, the construction account makes very little distinction between on-line and post-list processing, or between perception of a stimulus in the moment that it is presented and remembering of the stimulus a moment after it has disappeared. The same processes are assumed to be involved in both activities, imposing organization and meaning on physically present stimuli or on memorial records of earlier processing of those stimuli. The biggest difference between that account and the type/token account is that, according to the latter, knowledge of identity and repetition are acquired simply by activating a representation; whereas, by the former, those characteristics are imposed on or attributed to a stimulus, based on interpreting whatever evidence the subject has that seems relevant. That interpretation may be biased by processing performed before, after, or during the stimulus presentation. In the words of Marcel (1983), the mind attempts to "make sense of as much data as possible, at the most functionally useful level" (p. 238).

General Discussion

The present experiments demonstrate that the concepts of activation and inhibition of type representations are neither necessary nor sufficient to explain the variety of performance that can be observed when subjects view rapid word lists. As indicated in the introduction, those same concepts have been applied to a wide variety of other remembering and perceptual phenomena. However, there is growing evidence that activation and inhibition are inadequate to explain those phenomena as well.

As an example, most explanations of the semantic priming effect have invoked spreading activation, either alone or in conjunction with other processes (Anderson, 1976, 1983; Collins & Loftus, 1975; Collins & Quillian, 1969; Meyer & Schvaneveldt, 1971; Neely, 1977, 1991; Neely & Keefe,1989). Such accounts are motivated by two aspects of the effect that are commonly observed: first, that performance is facilitated when probe words follow a related prime, and second, that that effect is severely restricted in duration, occurring only over a span of about two seconds and at most one intervening item (e.g., Neely, 1977, 1991; Ratcliff & McKoon, 1988; Joordens & Besner, 1992; McNamara, 1992; Masson, 1995). However, the data supporting this characterization of the effect have been observed in studies primarily using two tasks: naming or lexical decision. Those tasks are not the only ones in which people might engage in semantic processing, nor are they even representative of ecological conditions under which people ordinarily engage in such processing. Becker, Moscovitch, Behrmann, and Joordens (1997) and Joordens and Becker (1997) instead asked subjects to classify prime and probe words as animate or not. Using this more elaborate and demanding task, they observed large semantic priming effects up to lag 8, and even observed moderate effects at lags 10 and 21.5. Hughes and Whittlesea (2003) went a further step, presenting different conceptual questions for each prime-probe pair. Under this combination of demanding task and distinctive processing, we observed large semantic priming effects enduring over a lag of 90 intervening trials and half an hour.

These observations are difficult for the spreading activation account to explain. The short time course of the effect in the earlier observations was taken as critical evidence in favor of spreading activation: just as in a neural network, activation within a semantic network could be expected to be a transient phenomenon, dying away quickly and leaving no residual effects on subsequent performance. The long time course observed in the latter experiments instead suggests a permanent change in the system (i.e., learning). It could be explained by introducing a new assumption, of enduring activation, but that assumption violates the original logic for invoking activation, and adds nothing that is not said by thinking of priming as a learning effect (which is why activation has rarely been proposed as an explanation of repetition priming).

Hughes and Whittlesea also observed that the long-term effect occurred with questions of various levels of conceptual abstractness, but did not occur when the level of question changed between prime and probe presentations. That rules out the possibility that long-term priming is mediated by activation of some abstract, context-free representation of the meanings of the prime and probe (i.e., hypothetical "type" representations). Instead, it suggests that long-term semantic priming occurs when the task required on the probe requires the person to recapitulate specific aspects of the processing performed on the prime (cf. Kolers, 1973, 1976). Like the current demonstrations, that evidence suggests that activation is neither necessary nor sufficient to explain critical phenomena of memory.

The concept of inhibition has been widely used to explain phenomena involving decrements in performance. As an example, in negative priming experiments, subjects are asked to selectively attend and respond to a target while ignoring distractors in each of two consecutive displays. Negative priming (slowing of response) occurs when the target in the second display corresponds to the distractor from the first display. Inhibitory accounts of the effect (e.g., Neill, 1977; Tipper, 1985; Tipper, Meegan & Howard, 2002) propose that selection of the prime target in the first display requires inhibition of the memorial representations of distractors, and in consequence those distractors are not as accessible when presented in the later probe display. However, a number of recent investigations raise problems for that explanation. DeSchepper and Treisman (1996) reported negative priming effects with a lag of 30 days intervening prime and probe displays. Though most inhibition accounts make no explicit assumptions regarding the duration of inhibition, it seems unlikely (and disadvantageous) that inhibition of a briefly encountered distractor would persist for such a long time. Moreover, negative priming can be observed even when subjects are not required to select against distractors (Milliken & Joordens, 1996; Milliken, Joordens, Merikle, & Seiffert, 1998; Ortells & Tudela, 1996). To explain these effects, Wood and Milliken (1998) proposed an explanation based on transfer-appropriate processing (Morris, Bransford, & Franks, 1977). By this account, negative priming occurs in the selection procedure not because subjects need to inhibit competing distractors, but instead because the processing done on the prime distractor is not appropriate to support the processing required of the probe task. That is, negative priming effects are determined not solely by encoding of the prime display, but rather jointly by the processes invoked at encoding and at retrieval.

Inhibition has also been invoked in explanations of reduced ability to remember. In investigations of the "directed forgetting" phenomenon, subjects are given a list of words to study; after the list, they are told to forget the list. They then study a second list. In a surprise test, in which they are asked to remember both lists, they recall fewer words from the "forget" list. This effect has been interpreted as showing that the "forget" instruction caused the subjects to retrospectively inhibit the set of items in that list (e.g., Bjork, Bjork, & Anderson, 1998; Bjork, 1989). However, Sahakyan and Kelley (2002) have shown that "forget" instructions may lead to reduced recall, not through inhibition, but through contextual change. In one study, the standard "forget" instruction was given; but prior to the test, half of the subjects were asked to remember their impressions of all that had happened from the moment of entering the room until the beginning of presentation of the first list. That procedure substantially increased remembering of the first list. Sahakyan and Kelley suggested that that effect resulted from reinstating earlier context at the time of the test; by implication, that means that the forgetting that occurred when such elaborate reinstatement was not required resulted from a change in the effective context of study for the "forget" and subsequent lists. Sahakyan and Kelley tested that idea in a second study, which also made use of context, but applied its logic in the reverse way. No "forget" instruction was given, but instead subjects were taken through an elaborate change in mental context between presentations of two lists. The results were similar to those observed in the standard "directed forgetting" paradigm, showing reduced ability to recall words from the first list. Thus, context change and "forget" instructions have parallel effects, suggesting a common mechanism involving the influence of context on retrieval success rather than inhibition of item retrieval. MacLeod, Dodd, Sheard, Wilson, and Bibi (2003) provide additional discussion of alternatives to inhibitory mechanisms in remembering and perception. (See also Sheard & MacLeod, this volume, for another non-inhibitory account of directed forgetting based on differential rehearsal, and Anderson, this volume, for further discussion of inhibition in memory.)

Why have activation and inhibition had such broad appeal as explanatory constructs? There are likely a number of reasons. First, the most obvious fact about human behavior is that it is controlled by the brain. The brain is known to operate by the principles of activation and inhibition; what more natural than to assume that mental operations can be explained in the same way? Second, activation and inhibition seem to provide a direct and simple answer to upward and downward changes in performance: because activation and inhibition clearly would result in increments and decrements in performance (inferring effect from cause), it is easy to make the argument the other way around, inferring cause from effect.[3] Third, if mental operations occur through activation and inhibition, then cognitive processes can be understood simply as due to quantitative variations, such as the probability that a mental unit (e.g., the type representation of a word) will be above or below a threshold of consciousness at any given time. That means that differing behavioral outcomes can be thought of as the result of variation only on a single quantitative dimension, of current strength or activation of the representation of a stimulus, without having to consider qualitative aspects such as the subject's perception of the goodness, completeness, or ease of their processing. That assumption also permits numbers to be assigned to such variation, making modeling of the process easier. Fourth, if activation and inhibition are the processing mechanisms of mind, then mind can be understood through an approach that is primarily architectural. Thus, for example, in spreading activation

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[3] In fact, the connection appears so direct that investigators often use the terms "activation" and "inhibition" interchangeably with the terms "facilitation" and "interference", and even with "increase and decrease relative to baseline", so that we have often heard statements like "we observed inhibition of performance when the subjects were required to . . ." However, the former terms refer to specific hypothetical constructs about causation, the middle terms to hypothetical relationships between one aspect of experience and another without implication of a specific cause, and the latter to observations of behavior (see also MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003).

network accounts, the structural details of the network itself—the degree of interconnectedness of nodes within the network, the number of layers necessary to account for separate knowledge of orthography, phonology and semantics, and the ways in which the network is wired to produce purely abstract, conceptual cognitions ("A triangle is a three-sided figure") versus episodic knowledge, associated with time and place ("I saw a triangle yesterday, on a blackboard")—are the important issues. Although complicated, such structural descriptions of mind are much easier to specify in absolute and concrete terms than are the processing assumptions of the construction-and-attribution alternative that we espouse.

We understand the appeal of activation and inhibition as explanatory constructs. However, as demonstrated by our experiments and those described at the beginning of this discussion, they simply cannot provide an adequate account of the range of phenomena in which psychologists are interested. One of the chief drawbacks to such accounts is that they have no ready way to incorporate or explain the phenomenology that accompanies perception and remembering. Under the assumption of such accounts, perception is simply the registration of a stimulus by means of activating its corresponding representation in memory; later remembering in the short term consists of reporting any highly active representations; remembering in the longer term consists of reviewing the contents of memory looking for appropriate tokens attached to concepts. Such a description leaves no room for the variety and richness of the ways in which perception and remembering can occur: not only with a clear feeling of identification or recall in the moment that they are required, but also occurring after an interval of being unable to do so, or occurring with feelings of doubt, surprise, or nagging and persistent familiarity.

In contrast, the construction-and-attribution account suggests that both perception and remembering are mediated through processes that are as much responsible for subjective reactions to the stimuli as report of the identity of a perceived or remembered object. In fact, it was attempts to explain subjective reactions that initially prompted interest in the attributional aspects of the account (e.g., Jacoby & Dallas, 1981; Jacoby & Whitehouse, 1989). For example, the SCAPE framework assumes that memory has two primary functions, each of which is engaged in every encounter with a stimulus. The first is the production function, consisting of a constructive and recursive interaction among the stimulus, context, current task or intention, and cued traces in memory of having performed similar activities on similar stimuli in the past. This function results in the production of a mental model of the current stimulus event, which will include those physical properties of the stimulus which are salient to the person, but will also involve abstract details contributed by the observer, such as the identity or class of the stimulus, or attributes of past or anticipated events involving that stimulus, such as repetition. This function results in the occurrence of percepts, cognitions, and overt responses. However, in doing so, it is modulated by the evaluation function, which monitors the integrity of the production (its fluency, completeness, and coherence). This evaluation causes the person to develop an attitude toward their performance. According to the framework, that is the source of the subjective experience accompanying performance, including feelings of knowing, remembering, humor, horror, and beauty. (The specific ways in which it does so are too complex to describe here. See Whittlesea, 2002a and 2002b for a full discussion.) This reaction to performance may cause the person to accept the produced mental content unquestioningly, interpret it in a particular way, or reject it out of hand. That is, by this account, the person's phenomenological reaction, which in the end governs the decisions that they will make about a stimulus, is not a direct product of the relation between a stimulus and a representation in memory, nor of the relation between prior experiences of stimuli and the current experience. Instead, it always critically involves an evaluation of the current contents of mind and their significance within the wider context within which the person is working.

We realize that this explanation seems to be needlessly complex to explain something as trivial as a person examining an A and reporting that they are perceiving an A. However, that example is not representative of much of life experience. Very often, people are in the position of experiencing complex stimulus displays, with many stimuli occurring simultaneously, each of which has properties of its own and relations with other stimuli. Further, such experiences in the world are usually dynamic and changing, so that there is not time to perform extensive analysis of much of the display. The processes that support perception and remembering under such circumstances are revealed by putting people under pressure, as for example by presenting divided attention tasks, large memory loads, or as, in the case of the repetition blindness effect, rapid presentation. Under such circumstances, the mental content resulting from the production function is often ambiguous, as might happen when a script capital A is presented tachistoscopically. In that case, the person is left with uncertainty, which must be resolved through an inferential and interpretive process which attributes those aspects of the experience of which the person is aware to the most plausible source in the environment or the past. Thus, the human mind does not simply record the impact of stimuli that it encounters; instead, in the words of Hobbes (1651/1967), the neural impulses caused by sensation "continue inward to the Brain, and Heart, causeth there a resistance, or counter-pressure, or endeavour of the heart, to deliver itself" (p. 10). That idea is the heart of the constructive account of perception and memory.

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Creation Theory of Cognition: Is Memory Retrieved or Created?

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Summary. It could logically be proposed that all of the symbolic responses that we make are "created" from stored serial impulse patterns, that we do not require any symbols or rules in our memory representations, and that memory and perception are based on the same processes. The simulations in this chapter indicate that a very simple algorithm can create a symbolic pattern from non-symbolic patterns without any symbols or any encoding rules in memory. The success of the simulation indicates the potentialities of the creation theory of cognition that regards the creation of symbolic information from the interaction between a vast store of non-symbolic information and the externally input non-symbolic information as "cognition."

Key words. Recognition memory, pattern recognition, cross-inhibitory processes, inhibition, memory representation

Is memory retrieved or created?

If you try to remember what was on the dining room table for last night's dinner, you probably perceive an image in your mind. Is this image the same as what you saw during last night's dinner? Or do you incorrectly believe that what you are recalling is in fact what you had seen?

There are two broad schools of thought in memory theories. According to one school, what one remembers is basically the same as the information content acquired by learning. According to the other school, the recalled information is different from what is stored as a result of learning. Here, for the sake of convenience, I shall refer to the former as *retrieval theories* and the latter as *creation theories* and try to determine which one of them is more appropriate, on the basis of behavioral data and simulation data.

The retrieval hypothesis is adopted more often than the creation hypothesis in models of human cognition. Typical examples are the theories where semantic networks are assumed to be memory representations (e.g., Anderson, 1983; Anderson & Bower, 1972, 1974a, 1974b; Atkinson & Shiffrin, 1971; Collins & Loftus, 1975; Collins & Quillian, 1970; Quillian, 1969). According to such theories, all of the information needed for cognition is considered to be stored in a form that can be easily retrieved. Moreover, a binary type of processing, in which the pre-stored target information is either accessed (activated) or not accessed, is assumed to be the basic mechanism of retrieval.

Tulving (1983) has explicitly opposed the retrieval theories. He claimed that an ecphory process, a type of interaction between the retrieval cue and the episodic memory trace (engram), occurs during the recall process of episodic memory, and that the ecphoric information created as an output of the ecphory process is crucial in testing of episodic memory. He pointed out that the expression "retrieval," which strongly suggests taking information out of storage, is out of place in explanations of memory recall.

Tulving (1983) did not propose a detailed theory of the ecphory process. But the idea of "creation" can be seen in some mainstream memory models like MINEVRA2 (Hintzman, 1984, 1986, 1988), TODAM (Murdock, 1982, 1993) and CHARM (Eich, 1982, 1985). For example, in MINERVA2, the concept (Hintzman, 1986) and the basics of recognition judgment (Hintzman, 1988) are assumed to be "created" at the time of retrieval, depending on the cue and other contextual factors (details will be discussed later). According to creation theory, memory is not fixed at the time of learning but is fairly variable and, keeping with the theme of this conference and book, dynamic.

Retrieval versus Creation

Assumptions about memory play an important role in understanding human cognition. Therefore, whether to adopt a retrieval theory or a creation theory is an important point of departure in understanding how memory content is stored and used. Many of the current cognitive models are based on the retrieval hypothesis and focus on how efficiently the contents are retrieved and processed (e.g., Anderson, 1983).

A reason why many models of general cognition are based on the retrieval theories is that this makes it easier to explain the cognitive phenomena. Cognitive phenomena can all be portrayed as a response (R) of humans to a stimulus (S). If we assume that the information on a perceived stimulus and the response to it are stored as knowledge, there is the advantage that when any new phenomena are observed, they can be explained by simply adding them to the memory representation. Almost all of human behavior can be explained if we assume that the S-R relation is stored in the knowledge representation in the form of a rule. Noting this, Hintzman (1982) stated that semantic network models, typified by the theory of Anderson (1983), are very powerful models that are difficult to refute.

But every persuasive theory is not necessarily true. In this chapter, I shall demonstrate the limitations of retrieval theories through a logical construction of the recognition memory mechanism.

Relation between recognition memory performance and familiarity

Most theories of recognition memory have been developed along the lines of signal detection theory, and have difficulty in explaining the "mirror effect." This is the phenomenon that is seen when high frequency (HF) words that you see very often in books and magazines and low frequency (LF) words that you do not see so often are used in recognition tests. False alarms to distracters are more frequent with HF words than with LF words, whereas the hit rates are higher for LF than for HF words. This is a persistently observed phenomenon that has been studied for many years (e.g., Gregg, 1976; Glanzer & Adams, 1990).

The assumption is that the familiarity of words before they are episodically learned (i.e., distracters) is greater for HF than LF words. If some of them are learned as targets, their familiarity increases. But the mutual relation between the familiarity of LF and HF should not change. However, in practice, the mirror effect makes the hit rate higher (higher familiarity) for LF than for HF target (learned) words. The fact that the explanation derived from signal detection theory and the actual results do not match is the reason why the mirror effect is always addressed in modeling of recognition memory.

A considerable amount of research has been aimed at explaining this phenomenon. But here, I shall focus on one assumption in these discussions—that "familiarity increases by learning." In other words, I shall look at the possibility of familiarity with a word not increasing monotonically with the increasing number of learning repetitions. If we assume that familiarity increases in a monotonic manner with learning, the mirror effect becomes a problem. But if familiarity does not increase monotonically, this would most likely prompt a reexamination of the problem of mirror effect.

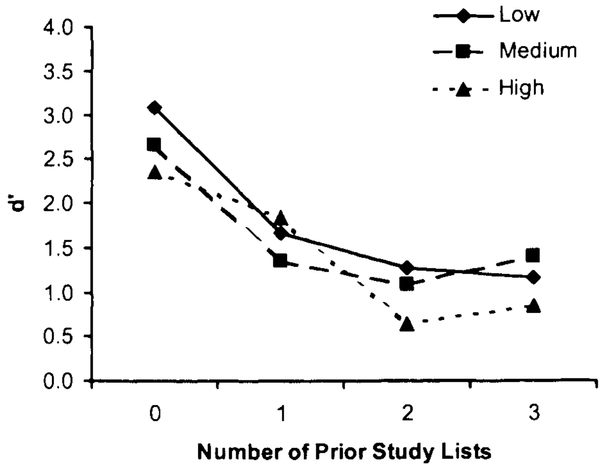

Fig. 1. Target list discrimination as a function of word frequency (low, medium, high) and the number of prior study lists (data from Terasawa, 1994, 1996).

Non-linearity of familiarity

Anderson and Bower (1974b) had subjects study lists of items and then decide at the time of testing whether each items had appeared in a specific list, a task that contains the fundamental elements of recognition judgment. Similarly, Terasawa (1994, 1996) has investigated in detail the change in recognition performance in relation to learning repetitions using this task. In my experiments, the subjects were asked to study separate lists containing all of the test items before studying the target list. I then examined change in the discrimination performance of the target list depending on the number of learning studied before studying the target list (= number of prior learning cycles: 0, 1, 2, 3: between-subject factor). Word frequency (high, medium. and low) was the within-subject factor.

In Figure 1, *d'*, the index of recognition performance, is plotted against the number of prior study lists for high, medium, and low frequency items. It can be seen that recognition performance decreased with an increase in the number of prior study lists. Anderson and Bower (1974b) reported similar results. They interpreted the decrease in discrimination performance as an interference effect originating from the prior studied lists.

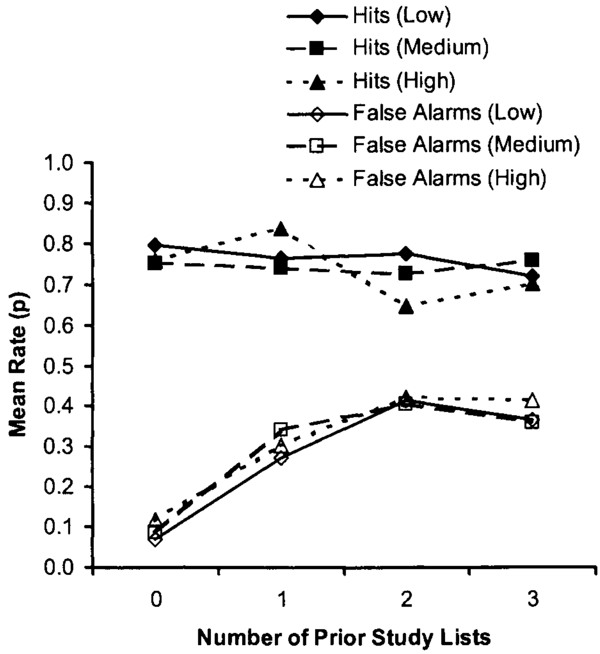

Fig. 2. Mean hit rate and false alarm rate as a function of word frequency (low, medium, high) and the number of prior study lists (data from Terasawa, 1994, 1996).

It is possible to understand the lowering of recognition performance seen in Figure 1 as a typical interference effect and to close the discussion there. The problem, however, is to identify the mechanism through which this interference effect manifests itself. Terasawa (1996) examined the *d'* data after classifying responses into hits and false alarms (Figure 2). In general, the hit rate did not change much with the number of prior learning cycles. But we can see that the number of false alarms increased significantly.

Here, the pattern of increase in false alarms is worth noting. In this experiment, the distracters also were involved in a certain number of learning cycles prior to the study of the target list. The number of false alarms clearly increased with an increase in the number of prior learning cycles. But the more important point is that false alarms did not increase linearly with the number of prior learning cycles.

From the false alarm data given in Figure 2, it appears that for subjects who were given the most learning cycles (i.e., 3 cycles), there was no effect of the excess repetitions on the rate of false alarms. In some ways, it appeared that the rate of false alarms was gradually coming up to the chance level. However, the false alarm rate is an index that can assume values in the range 0 to 1. So, there is a possibility of the false alarm responses occurring at least up to the level of the hit rate seen in each prior learning cycle. The rates of false alarms gradually becoming flat means that after a subject starts showing the "old" response to 5 out of 10 distracters, the "old" responses do not increase even if additional prior learning cycles are given. If this were so, the understanding that the rate of false alarms gradually comes close to the chance level would not be quite correct. A similar pattern in the relation between the hit rate and false alarm rate has been observed in some experiments where the number of prior learning cycles was taken as the within-subject factor (Terasawa, 1994, and unpublished data).

To explain the reduced increase of the false alarm rate, Terasawa (1994, 1996) suggested the possibility of familiarity showing a basically nonlinear change,. The conventional belief is that familiarity increases in a monotonic fashion. But if familiarity is basically non-linear, there is a possibility of the hit rate and the false alarm rate even decreasing with an increase in the number of learning cycles. In that case, the mirror effect becomes a phenomenon that can be explained well without the need to assume any special additional mechanism. In fact, if we compare the 1 prior learning cycle and 2 prior learning cycle conditions of high-frequency words, the false alarm rate increased but the hit rate decreased significantly (Terasawa, 1996). These results suggest that familiarity has non-linear characteristics.

On the basis of this analysis, it is therefore possible that familiarity has nonlinear characteristics. The important point here is not to discuss the linearity or non-linearity of familiarity but to specify the mechanism through which such characteristics are manifested. For now, we shall keep in mind the possibility of familiarity having non-linear characteristics and then proceed to examine the mechanism that can explain the pattern of increase in false alarms seen in Figure 2.

Explanation through list markers

It is possible to explain the decelerating increase of the false alarm rate seen in Figure 2 by assuming an interference mechanism as in the explanation of Figure 1, as given by Anderson and Bower (1974b). They considered the decline in *d'* shown in Figure 1 as a manifestation of interference between list markers. List markers are nodes that represent collections of context elements (each of which also can be considered as a node) arising from the presentation of specific lists. They are also called context nodes. They function as labels for collections of context elements. For example, when a word **W** is learned in the context of a list **x**, the context node **x** is connected to the node that represents the word (concept) **W**. When the same word is learned in the context of list y, the context node y is linked to the conceptual node **W**. Moreover, they argued that recognition judgment is based on the presence or absence (whether the link between **W** and **x** is evaluated or not) of such list markers (see Figure 3a).

Anderson and Bower (1974b) considered the type of decline in discrimination performance shown in Figure 1 as the effect of interference between list markers. In other words, the evaluation of a specific list marker is inhibited by another list marker that has been linked through the learning of similar lists. Similarly, the decline in the rate of increase of false alarms seen in Figure 2 could also be explained as the effect of interference between list markers. That is, with increase in the amount of prior learning, the number of non-target list markers increases, so that the probability of the target list marker being wrongly evaluated also increases. Under this idea, the reason for the suppression of increase in the false alarm rate would be the mutual interference between non-target list markers (Terasawa, 1994, 1997).

The single node problem

At first sight, the reduced performance in discrimination tests (and the decline of increase in false alarm rate) appears to be explicable through the concept of interference and contention between nodes. However, the concept of "interference" is itself difficult to handle in this type of theory where a single node is assumed, as we shall see now.

To begin with, interference and contention are concepts that are understandable only when two or more entities coexist "at a certain moment." In other words, two or more different objects are always assumed in the concepts of interference and contention. In discrimination tests, interference occurs among two or more list markers. Therefore, more than one list marker needs to coexist at one time. However, in a theory where a single network representation is assumed, a plural number of list markers cannot be considered to be the sources of independently existing information. I shall now elaborate on this aspect.

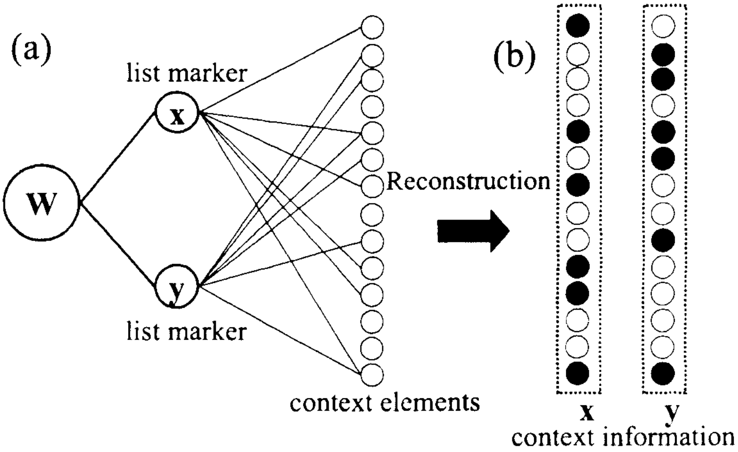

Fig. 3. The list marker concept and single nodes problem. The memory representation (a) and the reconstituted contextual information (b) needed for realizing the interaction between episodic memory contents when the word "W" is learned from lists x and y.

The two list markers x and y of Figure 3a may appear to be two different objects. However, list markers are nodes that represent context elements linked to them. Each context element node is unique. To produce interaction between the list markers, the episodic information expressed by the context elements corresponding to the list marker x and that corresponding to y need to overlap, at least partially, at a certain point of time. However, as long as a context element is represented by a single node, the episodic contents represented by a list marker can be expressed only one at a time in the memory representation. This is the same logic by which, for instance, the context elements corresponding respectively to list markers x and y of Figure 3a cannot be simultaneously represented in Figure 3a. To realize interaction among list markers, a mechanism that can retain the context elements represented by at least one list marker for some duration on a time axis is necessary. In a theory that assumes a single node, two objects cannot exist in a memory representation at the same point on the time axis.

The size of the interference effect of list marker y on list marker x is believed to depend on the similarity of the context information of the two list markers (Anderson and Bower, 1974b). To calculate its size, the collection of context elements (or a part of it) corresponding to x and y need to be temporarily reconstituted as in Figure 3b, for instance. To realize an interactive process such as interference, even temporarily, on the basis of a theory where a single node is assumed, it is necessary to hypothesize a new process that reconstitutes the contents of the context elements into a memory space such as a short-term memory. Terasawa (1994, 1997) gave the name "the single node problem" for this problem.

Catastrophic forgetting has been highlighted (McClosky & Cohen, 1989; Raaijmakers & Shiffrin, 1992; Ratcliff, 1990) as a fundamental problem that crops up when simulating episodic memory processing through connectionist models (e.g., Rumelhart & McClelland, 1986). With connectionist models, one condition is expressed over the entire network. Therefore, if the conditions of the units and the weights change following one learning cycle, it becomes difficult to simulate the effect of prior learning. As a result, regenerating the contents of specific prior learning cycles becomes difficult.

As in the case described above, there is a possibility of solving this problem by depicting the list marker representing episodic information as a node on the memory representation. However, in this case also, we encounter the aforesaid problem of the single node in explaining interactions such as interference that occur among multiple episodic contents. Similar problems are encountered by models like TODAM, CHARM, etc., where the memory representation is assumed to be a single structural entity.

Difficulties in identifying context elements

The process of reconstituting the context elements that correspond to every list marker is itself fundamentally difficult to realize in a theory. This is because, to reconstitute the context elements, firstly, the nodes (list markers) that represent the context elements of individual learning episodes need to be identified from the information presented at the time of testing. The instruction issued during a discrimination test (or even in an ordinary recognition test) just says "Have you learned word **W** of list **x**?" where the information relating to the non-target list **y** (list marker **y**) is not shown to the subject. In other words, even if access to the list marker **x** is possible, access to the list marker **y**, which causes the interference, is not guaranteed. Therefore, it becomes necessary to separately assume a process that identifies the non-target list marker **y**.

Moreover, to identify the node that interferes with the list marker **x**, it is necessary to judge whether each of the list markers linked to the concept node **W** would interfere with the list marker **x**, through similarity level computation, etc. In assuming that such a process occurs, we would again encounter the aforesaid single node problem. In other words, in a theory where list marker type content is postulated, it is difficult to identify episodes that are not explicitly contained in the search cue and to reconstitute such episodic information. Terasawa (1997) called this problem "difficulty in identifying context elements."

Multiple trace theory of memory representation

One way of solving the single node problem is to apply the multiple trace theory of Hintzman (Hintzman, 1976; Hintzman & Block, 1971; Hintzman et al., 1982; Hintzman & Stern, 1978). In the multiple trace theory, it is assumed that when the same word is studied several times in different contexts, this information is all stored episode-wise as unique traces (episodic traces). If we assume that episodic contents are essentially stored in unique individually independent memory traces, it becomes easy to realize interactions between episodic contents, such as mutual interference, and the problem of single node can be naturally solved. The assumption that episodic information is stored as independent information sources can be seen in SAM as well (e.g., Gillund & Shiffrin, 1984; see also Clark & Gronlund, 1996).

Mechanism of the process that generates non-linearity of familiarity

So far, keeping in mind the possibility of familiarity having non-linear characteristics, I have examined the assumptions of memory representation required for a mechanism that can generate such characteristics. As a result, it became clear that for hypothesizing interactive mechanisms like interference, it must be appropriate to assume that unique and independent information is stored in each learning episode.

SAM and MINERVA2 are models in which multiple independent traces are assumed for memory representation. The major difference between these models is that SAM is based on a retrieval theory whereas MINERVA2 is based on a creation theory. In MINERVA2, the information finally output in memory tests is information newly created on the basis of multiple memory traces, whereas in SAM it is specific individual episodic information, called an "image" (Raaijmakers & Shiffrin, 1992).

For modeling a mechanism of recognition using a retrieval theory that includes SAM, we may postulate an evaluation process that calculates the probability of information about the target, or similar information, existing in the memory representation. The important point here is that the retrieval theories have the characteristic that this probability increases monotonically with increases in the amount of information, similar to the target in the memory representation. It is basically difficult to envision the possibility of a decrease in this probability.

In MINERVA2, intensity is postulated as the value on which the recognition judgment is based and is assumed to have a non-linear function. In the following discussion, I shall take up MINERVA2, identify the problems with this model, and turn the discussion to my own separate theory.

MINERVA2

In MINERVA2, each study event is represented as a list (vector) of feature elements. It is mapped into memory at the time of encoding. At the time of recognition judgment, the traces stored in memory are activated in a parallel fashion according the value of similarity (Si) with the probe stimulus. Each similarity cube is called *activation* ($Ai=Si^3$). The sum of the activation values of all the traces is called *intensity* (intensity $=\sum Ai$), and is used as the basis for recognition judgment. The contents of each trace multiplied by activation and summed over all the traces is called *echo*, which is assumed to be used for recall, category judgment, etc.

MINERVA2 may be considered as the only creation theory-based model where a multiple trace theory is used for memory representation. In this chapter, I label the MINERVA2 assumption that the information source corresponding to each study episode is stored in an independent form the *independent representation hypothesis*. Similarly, I label the assumption that the information used in cognitive judgment by humans is different from the stored information and is newly created the *creation hypothesis* of cognition. If we classify the major memory models suggested so far according to whether they assume independent multiple traces and whether they employ the creation hypothesis, we get Table 1.

MINERVA2 is based on the independent representation hypothesis and the creation hypothesis. But we could not say that this model explains in a simple fashion all the memory phenomena related to recognition and recall. For example, it has been pointed out that there is a difficulty in outputting specific episodic information (recall) on the basis of the echo (Raaijmakers & Shiffrin, 1992). Besides, although the intensity is calculated using a non-linear function, we cannot envisage that it would ever decrease, although it may increase when the same word is studied repeatedly in a similar context. Thus, even in MINERVA2, the mirror effect is a phenomenon that is difficult to explain.

Table 1. Classifying models according to retrieval/creation and single/multiple representation distinctions.

	Single representation hypothesis	Multiple representation hypothesis
Retrieval hypothesis	Semantic Network Models, ACT*s, (Connectionist models)	SAM
Creation hypothesis	TODAM, CHARM, Matrix	MINERVA2, UME

Classifying connectionist models depends on whether they assume an output element that represents a symbol.

In this chapter, I shall suggest, on the basis of the independent representation hypothesis and the creation hypothesis, a unique processing algorithm (UME), which is different from MINERVA2, and which does handle the mirror effect. Before proceeding to a detailed discussion of UME, I shall explain my views about memory representation.

Do humans store symbolic information?

Researchers have used a variety of terms to refer to the information and knowledge that human beings store. These include the earlier mentioned concept nodes of semantic networks, episodic traces of the multiple trace theory, images, elements corresponding to characteristics detectors of the PDP model, mental lexicons, etc. In most cognitive theories, the presence of such symbols existing as knowledge (memory) representations is taken as a precondition. A number of cognitive phenomena have been successfully explained by assuming that such symbols are used by human beings for outputting responses (behavior). In other words, current cognitive theories widely accept that human beings generate responses and behavior through manipulation of these preexisting symbols.

However, there has been very little discussion on the mechanisms by which symbols are acquired. For example, the concept node that represents the numeral “2”, i.e., the process of formation of the characteristics detector that detects the horizontal bar (-) used for pattern recognition of “2”, has not been clarified. It is easy to assume that basic characteristics detectors are inherently present in human beings. But would it not be possible to model the human cognitive phenomenon from a different point of view?

You perceive a straight line in Figure 4. Your eyeballs execute saccade movements about three times every second. The process that converts the optical information provided by the visual cells into impulse data depends

Fig. 4. No linear information has ever been input into you from the time of your birth.

on chemical reactions in individual visual cells. It would not be appropriate to assume that the timing of the output impulses is the same in all of the visual cells. In other words, it is very likely that at a given moment when you observe the straight line of Figure 4, the impulse data being input into your brain is almost random information. This state of affairs has continued from your birth to the present moment. It means, if we think naturally, we can conclude that human beings never receive symbolic information.

Taking this into consideration, Terasawa (1994, 1997) postulated that information possessed by humans is binary-type non-symbolic pattern information (n-s pattern information, for short) that is output by receptors into the human body and the brain. I suggested the approach of explaining the cognitive process in human beings from the vast amount of n-s patterns that we hold. According to current cognitive theories, the responses (speech, etc.) that human beings finally output are all based on symbolic information that they already possess. A lot of effort is spent in elucidating the processes for accessing such symbols in response to external stimuli. Contrary to this, Terasawa (1994, 1997) argued that the information held by human beings consisted of n-s patterns, and emphasized the need for an approach to elucidation of the processes that finally generate (create) such symbolic information.

According to this view, it is assumed that human beings retain the n-s patterns almost as such. Therefore, there is no need to postulate processes for encoding the external n-s patterns, collating them with internal symbols, and storing them. What becomes difficult then is the modeling of the symbolic cognitive process from the n-s pattern information alone, which human beings accomplish. The outcome of this approach depends on whether the symbolic information that human beings output can be created solely from the accumulated meaningless patterns.

Assumptions of the spiral representation theory

Hintzman, who is a major proponent of the multiple trace theory, has been insisting for a long time on an independent representation hypothesis. In spite of this, sufficient attention might not have been paid to this aspect. In this article, I give attention to multiple trace theories and develop my own memory representation theory, taking note of the importance of the independent representation hypothesis of Hintzman and identifying the problems of the multiple trace theory.

One of the problems of the multiple trace theory is that symbolic meaning is assumed for the information that constitutes the episodic trace. For example, Hintzman (1988) assumed that sequence information, such as "before" and "after" information, is present in "slots" of episodic traces. But there is no explanation of how the slot itself, which represents a characteristic element often used for explaining the model, is expressed or formed. The theory takes the standpoint of symbolism.

Another major problem with the multiple trace theory is the fact that experience, which is fundamentally a continuous entity, is divided into units of episodes (events). Episodes actually acquire their labels at a later stage. Therefore, it does not seem rational to assume that specific events are encoded as episodic traces at the time of their learning, in a cut-up fashion, in a process that continues on a time axis. For example, it is difficult to think that an episode that involved, say, a cable car ride that you enjoyed in San Francisco and an episode of dining on Italian food in Eugene during your travel in the west coast of U.S., are recognized as independent episodes and stored compartmentally. Episodes are identified and acquire starting points and endings for the first time when they are recalled.

Taking these facts into consideration, Terasawa (1994, 1997) suggested the inclusion of a time axis in memory representations and postulated memory representations of the type shown in Figure 5b.

Figure 5b is a conceptual diagram of the spiral representation theory. In this theory, the memory representation is assumed to have a receptor axis and a time axis, and binary type impulse data that are continuously output from receptors (or any other organ of the body) to the brain are statically stored almost as such.[1] It is assumed that even if similar information is input from the same receptor, etc, it functions as a different source of information if the time of input is different. This is why the expression "spiral" is used. In Figure 5, I have compared the conceptual diagrams of the multiple trace theory (**a**) and the spiral representation theory (**b**).

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[1] It may not always be stored as such but we shall proceed with the discussion on the basis of this assumption.

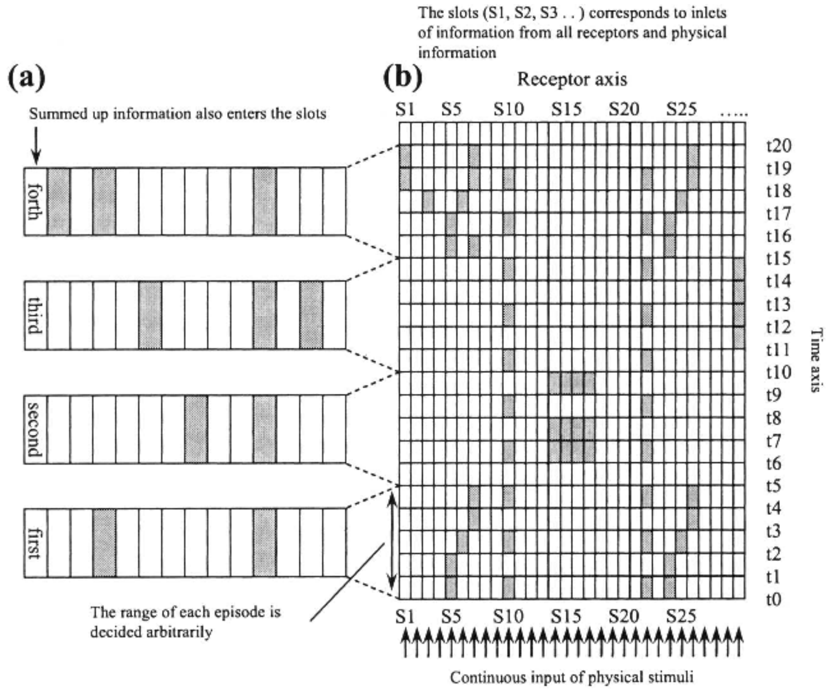

Fig. 5. Comparison of the multiple trace theory and spiral representation theory. Hintzman's multiple trace theory (a) and the representation theory proposed in this article (b). The time axis indicates the passage of time in the sequence t0, t1, t2. S1, S2,... of the receptor axis (abscissa) represent inlets.

Activation Inter-Restraint Theory

Taking this spiral representation theory as a precondition, I shall now advance the discussion on the processing mechanism.

First, like the multiple trace theory, it is possible to realize the independent representation hypothesis for the spiral representation theory by assuming the activation process described below. Terasawa (1994, 1997) postulated a time axis within the memory representation and also external input, and assumed that when a cognitive process is demanded, depending on the external information input, similar parts within the memory representation are activated. It is further hypothesized that as a result of this activation process, the activated parts function as independent information sources (see Figure 6). In other words, by assuming an activation process for spiral representation, it becomes possible to create independent multiple information sources and to model the interactions that occur among them. I consider that the information sources corresponding to episodic traces are *created* for the first time when a cognitive judgment is called for. In addition, I postulate that the execution of a cognitive task is not done instantaneously, but always takes a certain amount of time[2].

According to the process assumed in MINERVA2, the intensity, used as the basis for recognition judgment, would have the characteristic of monotonic increase when the same item is repeatedly studied in similar contexts.

On the other hand, I suggest the possibility of familiarity itself having nonlinear characteristics, from the decrease in the increasing rate of the false alarm rate seen in the discrimination test performance shown in Figure 2. Besides this, I suggest the need to have an interference mechanism for the output of familiarity to explain the decrease in the increasing rate of the false alarm rate. Terasawa (1994, 1997) then proposed an *Activation Inter-Restraint (AIR) theory* for the cross-inhibitory mechanism among the activated information traces.

The moment a recognition judgment about a certain item is demanded, according to external information provided, all the similar trace information sources are activated in parallel (the activation process) and information source traces are created. In addition, a process of mutual restraining of the activated information traces (inter-restraint process) is also hypothesized. The sum of activation of all the information source traces after adjusting for mutual restraint is termed the *restraint-corrected intensity* or R-intensity. It is proposed that this is the basis of familiarity judgment.

Apart from the proposed inter-restraint process, the same processes as in MINERVA2 are assumed in the mechanism of recall. The activation level of each information source, reduced by the inter-restraint, multiplied by the n-s pattern of the original information trace and summed over the whole of the trace information pattern, is termed the *restrain-corrected echo* (R-echo). It is assumed that this R-echo is used for recalling and creating symbolic information (this aspect will be discussed later).

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[2] Postulating a time axis in the memory representation and the cognitive process has profound significance. I shall explain its significance and how the memory representations are actually realized on another occasion.

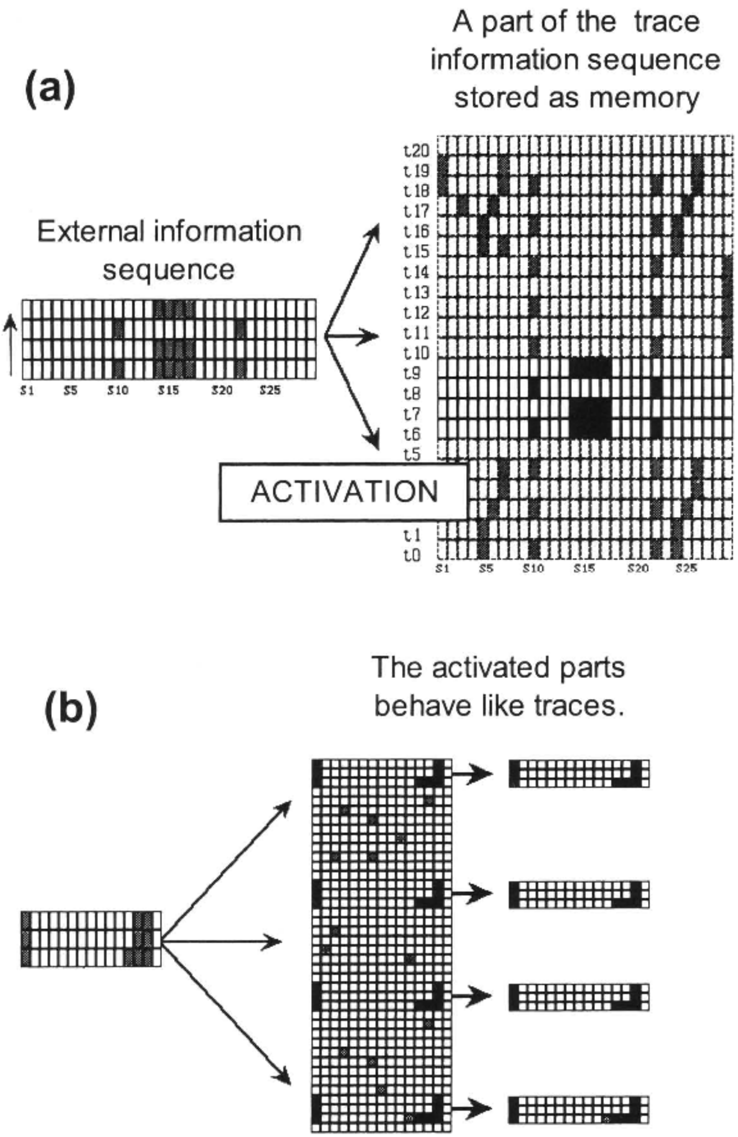

Fig. 6. The hypothesis of activation (a) and the trace information sources formed in memory representation (b). When external information is provided, the part similar to it in the memory representation is activated.

Other assumptions

Currently, there is no theory that postulates a cross-inhibitory mechanism for the output of familiarity, which is the basis of recognition judgment. This inter-restraint mechanism is the main feature of the AIR theory.

In the cross-inhibitory mechanism of the AIR theory, it is further assumed that the higher the activation of an information source trace, the stronger is its restraining activation on all other information source traces (see Terasawa [1994, 1997]). According to this theory, the results of output of familiarity and the echo differ significantly, depending on whether information sources with a high degree of similarity to the external information are contained in the traces used for the processing. In other words, according to the AIR theory, the constituting elements of the system in recognition judgment differ between the targets and the distracters. When a target is encountered, trace information very similar to the cue stimulus (external information) exists in the memory representation and gets involved in the process of recognition judgment. On the other hand, for a distracter, trace information similar to the cue stimulus does not exist and the system has a much simpler structure.

Figures 7a and 7b show the outline of the recognition system postulated in the AIR theory, separately, for target and distracter. The constituting elements of the recognition system are different, depending on whether trace information similar to the external information exists. Therefore, Terasawa (1994, 1997) proposed that the recognition system should be separately discussed for targets and distracters.

Terasawa (1994, 1997) had predicted that the effect of study would be retained for a much longer period than what is currently assumed. I shall not go into a detailed explanation of this here. This prediction has been verified in several experiments. For instance, it has been shown that the effect of a few study repetitions consisting of barely 2 seconds of learning each can be detected after several months in Terasawa (1994, 1997) (see also Terasawa, 2001, 2003). On the basis of these results, I had proposed the hypothesis that memory persisted permanently (the hypothesis of memory permanence). Thus, I consider that in modeling the cognitive system, there is a need to avoid underestimating the effect of encounters with stimuli not directly related to the experiment and experienced a long time ago, to incorporate the traces attributable to such experiences into the cognitive system, and to take their effects into account. The reason for intentionally including non-target traces, recorded before the experiment, in Figure 7 is to ensure that such traces are taken into account.

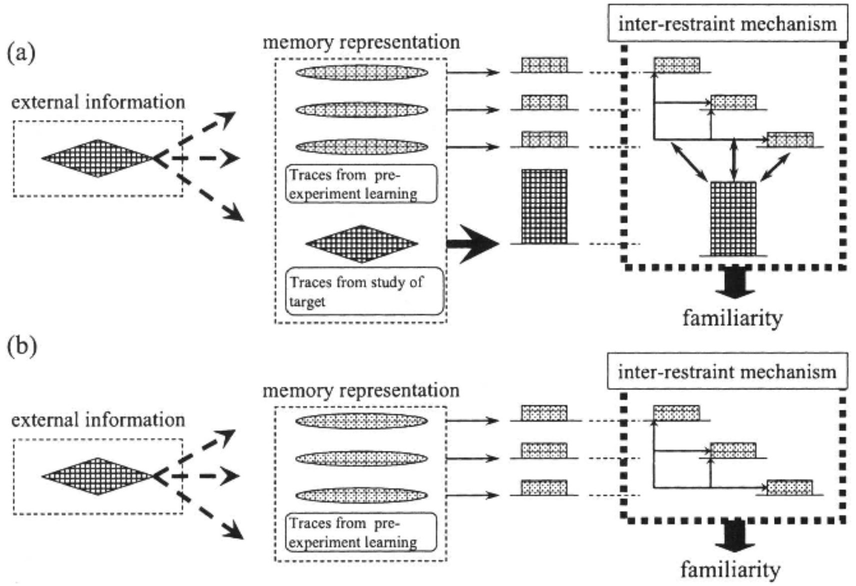

Fig. 7. An outline of the AIR (Activation Inter-Restraint) theory. The recognition system postulated for target recognition (a) and the recognition system postulated for distracters (b).

I shall now introduce the results of a simulation of recognition memory performance by the UME model, developed on the basis of the AIR theory.

Simulation of familiarity by UME

For simulating familiarity using the UME model, the parameters are set with the following three restrictions:

1. Traces concerned with the calculation of familiarity are restricted to three types, namely: (i) traces attributable to pre-experiment experiences (low similarity with external information); (ii) traces attributable to study of non-target lists (medium similarity with external information), and (iii) traces attributable to study of the target list (high similarity with external information).
2. The simulation is carried out separately for the cases where traces attributable to study of the target list exist (target) and cases where such traces do not exist (distracter).
3. The same words are repeatedly studied from non-target lists and after that they are seen once in a target list. The condition necessary for rec-

ognition judgment of the target list is laid down and the model examines how the familiarity changes for the number of learning cycles with non-target lists.

The following seven parameters were set: (1) initial value of trace similarity attributable to pre-experiment experience, (2) number of trace information sources attributable to pre-experimental experience, (3) initial value of trace similarity attributable to non-target learning episodes (study of non-target lists), (4) number of traces increased as a result of the non-target learning episodes (abscissa), (5) weight of inter-restraint ($W < 0$), (6) number of inter-restraint cycles used in the simulation, and (7) trace similarity attributable to study of the target list (not postulated for distracters).

The similarity (Si) between the external information and each stored trace information source is calculated, and the inter-restraint process of traces with high similarity lowering the similarity of all other traces to an extent that depends on similarity is carried out for all possible combinations of traces using Equation 1 (W is the negative coefficient of inter-restraint and M is the total number of traces). Here, there is no need to continue computation of inter-restraint up to the point of stabilization. The sum of similarities of the traces after executing a certain number of inter-restraint cycles is taken as familiarity.

$$dS(i)/dt=W\{\psi(S(1))+\psi(S(2))+\bullet\bullet+\psi(S(i-1))+\psi(S(i+1))+\bullet\bullet\ \psi(S(M))\},\quad \psi(x)=\{x(x>0),\ 0(x\leqq 0)\} \qquad (1)$$

The results of simulation for distracters and targets are shown in Figures 8a and 8b. The pattern varied depending on the values of parameters, but the basic qualitative characteristics were as shown in these figures. It became clear that familiarity did not increase monotonically for both distracters and targets.

No one has so far suggested a theory in which an inter-restraint processing mechanism is postulated for the output of familiarity. In retrieval theories, it is assumed that familiarity is fundamentally dependent on the accessibility of the target information sources and that the interference attributable to non-target information may reduce accessibility, but would not make it less than 0. In other words, these theories have assumed that learning the same items repeatedly might increase familiarity, but it can never decrease familiarity.

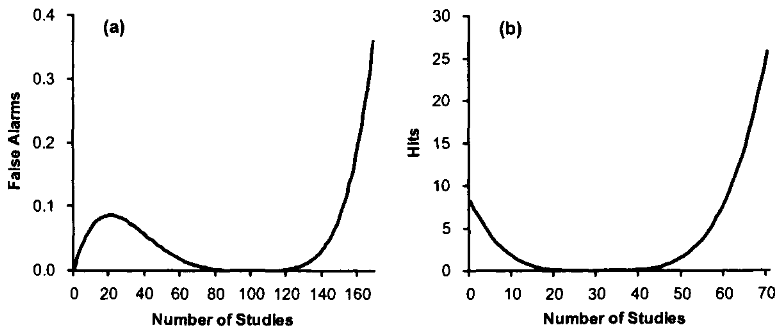

Fig. 8. Results of simulating familiarity for (a) distracters (false alarms) and (b) targets (hits) on the basis of AIR theory (with the assistance of Souko Tanaka and Seiichi Tsujimura: unpublished data).

Simulation of recall and symbol creation by UME

Tsukahara and Terasawa (1997) tried simulation of symbol creation from n-s patterns by applying the assumptions of the spiral representation theory regarding the n-s patterns to MINERVA2. To be more specific, instead of the episodic traces of MINERVA2, handwritten numerals were stored in a multiple secondary memory as images. Handwritten images were also used as recognition probes and the formation of echoes was simulated. The simulation process of Tsukahara and Terasawa (1997) is almost identical with the process of echo generation in MINERVA2, except for the already described assumptions about the stored information.

Figure 9 shows the result of simulating the echo output by MINERVA2, following a procedure similar to that of Tsukahara and Terasawa (1997). The images in boxes under the label “SM” are the trace information sources (created “traces”) and the image under “probe” is the pattern input as external information. Also, the image shown under “choice” adjacent to the echo is that of the trace with the highest similarity with the external information, retrieved as such.

MINERVA2 could often succeed in creating an echo that can be called a symbol when images similar to the probe are stored (Tsukahara & Terasawa, 1997). However, as is shown in Figure 9, MINERVA2 could never generate a symbolic echo when variations of traces become larger.

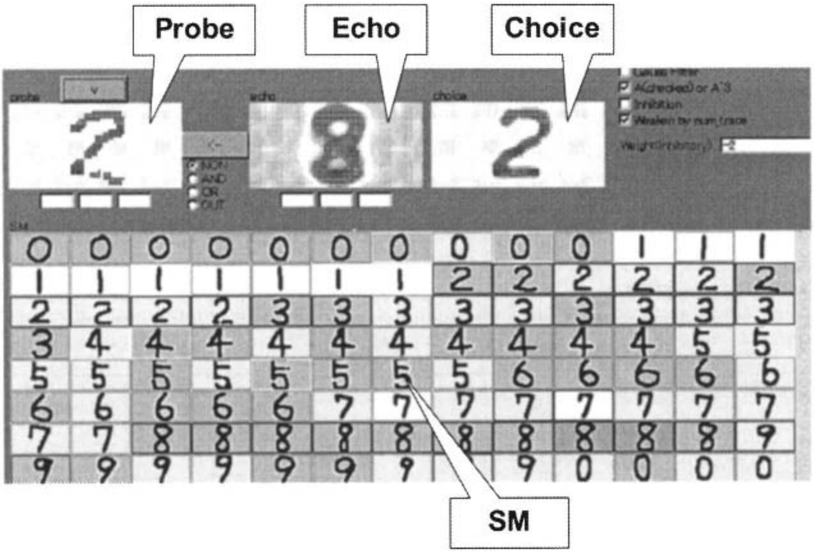

Fig. 9. Results of simulation of recall and symbol creation by the MINERVA2 model.

In contrast, as shown in Figure 10, UME can create a typeface-like pattern that we can easily recognize as the numeral "2" as the echo (other sample results are shown in Figure 11). There is no pattern in SM identical with this created echo. Furthermore, among the stored traces, there are some images with thick black frames. These are the images whose similarity with the probe after applying the inter-restraint was high. This means that the contents of these images were used for synthesizing the echo. In other words, the contents of multiple traces are reflected in the created echo. This shows that UME can create new symbolic information that did not exist as a trace earlier, by using a number of stored non-symbolic information sources.

Of course, the UME system does not have any inbuilt rules for forming typefaces. Also, the information stored in SM consists of the image data only. No information as to which image corresponds to the numeral "2" or numeral "1," etc. has been entered. What exists is individual trace information plus the external information newly input at each time of processing. Neither of these contains any symbols. No feature for making the echo look more like a typeface has been added to the simulation model. Despite this, a pattern that looks very much like a typeface is created, which is nothing short of mysterious.

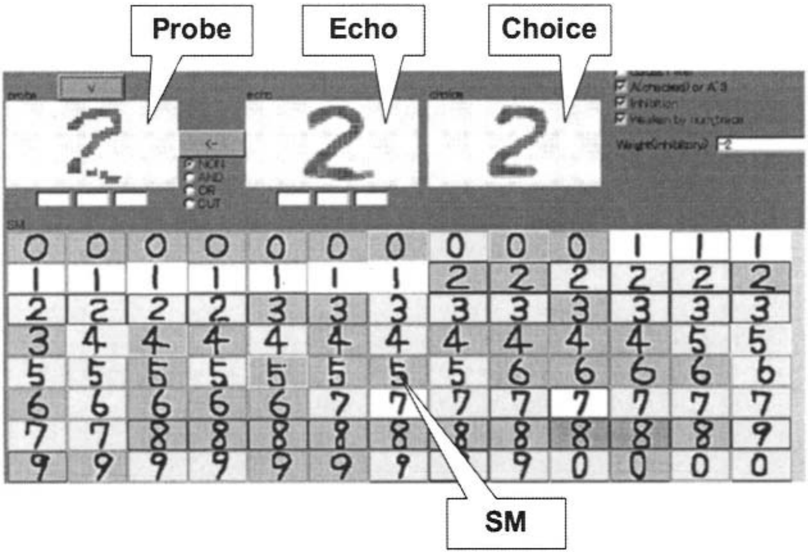

Fig. 10. Results of simulation of recall and symbol creation by the UME model.

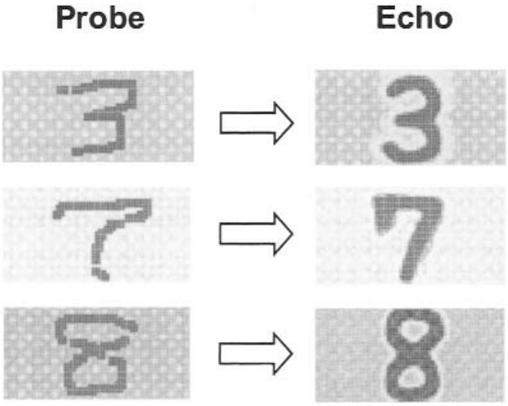

Fig. 11. Sample results of symbol creation by the UME model.

This simulation demonstrates that symbolic patterns that humans recognize can be created from a number of non-symbolic patterns alone. Many conventional cognition theories postulate the existence of internal symbols and try to explain the cognition process through their manipulation. On the contrary, this simulation model illustrates the possibility of creating symbolic information from binary type pattern information and also of creating symbols of even a higher order using such information.

In the present chapter, I consider some problems of memory representation theories that assume a single structural entity (single representation hypothesis) and the validity of the multiple representation hypothesis (e.g., Hintzman, 1976). In addition, I attach much importance to the creation hypothesis, supposing that what we output at the time of a cognitive or perceptual judgment is information created from a vast amount of information stored earlier together with externally input information. Furthermore, I question the symbolism that supposes we hold a number of symbols in our memory, encode a non-symbolic stimulus with respect to preexisting symbols, manipulate such symbols, and output symbols as cognitive tasks require. Instead, I argue in this chapter that we store binary type non-symbolic information continuously output from receptors to the brain and that we create symbolic information from the accumulated non-symbolic information.

In short, I discussed the following alternative opposing argument in this chapter.

1. single vs. multiple: episodic information input at a certain point of time is represented within a single entity vs. as multiple unique information sources;
2. retrieval vs. creation: output information is retrieved vs. created; and
3. symbolism vs. non-symbolism: stored and output information is symbol vs. non-symbol.

Most current cognitive theories suppose that, at the time of learning, human encodes external information into preexisting symbols on a single representation, and retrieve them at the time of cognitive judgment. On the contrary, the theory proposed in this chapter argues that we continuously store input non-symbolic patterns, and at the time of cognitive or perceptual judgment we create new symbolic information that has not exist earlier by using a number of stored non-symbolic information sources together with the external information newly input each time cognitive or perceptual processing is required. This chapter proposes a creation theory of cognition where the creation of symbolic information from the interaction between a vast store of non-symbolic information and the externally input non-symbolic information is considered to be "cognition."

The outcome of this approach depends on whether the symbolic information that we output can be created solely from the accumulated non-symbolic information. I illustrate the AIR (Activation Inter-Restraint) theory that supposes a cross-inhibitory process in cognitive or perceptual processing. The simulation model (UME) based on this theory succeeded in creating a symbolic pattern solely from non-symbolic patterns (see Figures 10, 11). The success of the simulations indicates the potentialities of the model for processing non-symbolic information that is difficult to encode, and for outputting new symbolic information or rules solely from non-symbolic information, showing the validity of the creation theory of cognition.

Author Notes

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http://ed-www.ed.okayama-u.ac.jp/~shinri/terasawa/ume/

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The Role of Inhibitory Control in Forgetting Unwanted Memories: A Consideration of Three Methods

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Summary. When confronted with reminders to things that we would prefer not to think about, we often attempt to put the unwanted memories out of awareness. Here, I argue that the ability to control memory is a special case of a broad class of situations thought to require executive control: response override. In such situations, one must stop a strong habitual response to a stimulus due to situational demands, a function thought to be accomplished by inhibitory processes that suppress the response, enabling more flexible, context-sensitive control over behavior. Recent behavioral studies show that inhibitory mechanisms that control overt behavior are also targeted at declarative memories to control retrieval. Recent neuroimaging findings (Anderson et al., 2004) further establish that controlling awareness of unwanted memories is associated with increased dorsolateral prefrontal cortex activation, reduced hippocampal activation, and impaired retention of the unwanted trace and that the magnitude of activation in prefrontal cortex predicts memory suppression. These findings indicate that cognitive and neural systems that support our ability to override prepotent responses can be recruited to override declarative memory retrieval, and that this cognitive act leads to memory failure. The relation between these findings and those obtained with the directed forgetting procedure is also discussed.

Key words. Inhibition, executive control, forgetting, prefrontal cortex.

Introduction

In the film *Eternal Sunshine of the Spotless Mind*, Joel suffers from the pain of a broken relationship with his former love, Clementine. To rid himself of his pain, he visits a memory clinic and arranges to have all memories of Clementine erased from his brain. The deletion procedure involves presenting objects that remind Joel of Clementine while he has his brain scanned to construct a "map" of all the memories of Clementine that are in his brain. Once the Clementine map is constructed, technicians perform a memory "deletion" procedure. They go through this procedure in the convenience of Joel's home (while he is asleep in bed), erasing each memory, one at a time, through highly focused brain damage.

Although the technology imagined in this film may be far-fetched, the film highlights an important theme that often goes unappreciated: Sometimes it is not desirable to have good memory for an experience. Like Joel, we often encounter reminders to things that we would rather not think about. Whether we are reminded of a past relationship, a lost loved one, a violent attack, a task we would prefer not to do, or something as mundane as an old telephone number when a more recent one is desired, we are frequently disrupted by a memory system that is at times too efficient in delivering memories that we do not want or need. In these circumstances, we often exert effort to put these memories out of mind, and we may wish that a memory deletion device existed. Even concentrating on a single idea or train of thought relies upon the capacity to prevent ourselves from being diverted in the different directions our mind might wander based on spreading activation. Remaining focused requires controlling the retrieval of distracting ideas. Given its broad importance, a central goal of cognitive neuroscience ought to be to elucidate the mechanisms by which such control is achieved.

This chapter reviews the work done in my laboratory examining the mechanisms underlying the control of unwanted memories. Although the findings we have obtained are far from "memory deletion," they do indicate that people have some capacity to suppress unwanted memories. A core claim that my colleagues and I make is that this ability to control retrieval is supported by executive control processes of the sort that are widely studied in cognitive psychology and cognitive neuroscience, but targeted at declarative memories. Specifically, we argue that inhibitory control processes can be recruited to stop or override memory retrieval and thereby to exclude unwanted memories from consciousness, and that this cognitive act contributes to later memory failures for the excluded trace. By this perspective, an intimate connection exists between our many memory failures and the ability to control the direction of cognition.

The work discussed in this chapter is related to another line of research that examines the ability to control unwanted memories: directed forgetting (see Sheard & MacLeod, this volume). Although these lines of research have progressed separately, it is important to consider the relations between them, and how this may add to our understanding of the different ways in which memory control may operate. Thus, a second aim of this chapter is to discuss alternative views of the relation between the mechanisms involved in these different experimental approaches to the inhibition of unwanted memories. In so doing, a framework is offered with the goal of fostering theoretically targeted comparisons of these approaches. By isolating the mechanisms that contribute to motivated forgetting of past experiences, we may better understand the limits of our naturally occurring efforts to achieve a "spotless mind."

Executive Control and the Mechanisms of Retrieval

The current perspective begins with the observation that actions, once started, can usually be stopped. This fact was impressed upon me one evening while opening the kitchen window. As the window slid along its track, it pushed a cactus off the sill. My hand darted to catch the cactus. Mere centimeters from it, I stopped my hand from clutching the cactus's needle-dense body. This timely save was made possible by my ability to stop physical action—an ability so pervasive that it goes unnoticed in daily life.

The preceding case is a classic example of a situation in which we need to stop a strong habitual response, a situation widely regarded as requiring executive control. This is sometimes referred to as response override, and is illustrated in Figure 1. In response override, one must stop a prepotent response to a stimulus, either because the response needs to be withheld or because a less common response is more appropriate. The capacity to stop or redirect action in this way is crucial. Without it, we would lose flexibility to adapt behavior according to changes in goals or to changes in the environment. We would be slaves to habit or reflex.

But how do we keep from being automatically controlled by the habitual action? One widely discussed answer is that inhibition is used to suppress the habitual response. By this view, the appearance of a stimulus activates a representation of that stimulus in memory. Activation then spreads to associated responses in proportion to how strongly associated they are to the stimulus. When a response becomes sufficiently activated, it will be emitted. If there are multiple responses, the one that achieves threshold most quickly will generally be emitted. However, if a weaker response is more appropriate, inhibition can be recruited to suppress the stronger ones. Inhibition is thought to reduce the activation level for a given response, preventing it from achieving threshold. In so doing, weaker, but more appropriate responses can be expressed, enabling flexible, context-sensitive behavior. This is known as inhibitory control.

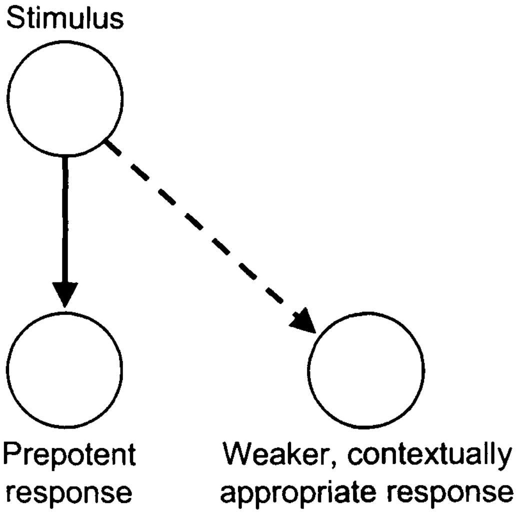

Fig. 1. A typical response override situation (e.g., Stroop or Go/No-Go tasks). Circles correspond to representations in memory, with lines representing associations between these representations. The stimulus is linked to two responses, one of which is stronger (prepotent), and the other of which is weaker (dotted line). Response override must occur when the organism needs either (a) to emit the weaker, but more contextually appropriate response, despite the stronger association to the prepotent response, or (b) to stop any response from occurring. Inhibitory control is thought to suppress activation of the prepotent response to permit response override. The response override situation characterizes many paradigms in work on executive function, including the Stroop and go/no-go tasks.

Given the importance of inhibitory control in managing overt behavior, one might ask whether internal actions might also be influenced by such mechanisms. Parallels exist between the control of action and the control of memory. Just as a stimulus may spread activation to a prepotent motor response, a retrieval cue may activate a strongly associated item in memory, leading it to be retrieved. The retrieval of associated memories is not always desirable; sometimes, we may wish to retrieve a memory associated to the cue; other times, we may wish to avoid retrieval altogether either because the memory is unpleasant or because we wish to maintain focus on the cue concept. Although we often retrieve things that we do not intend, we can control this tendency; we can recollect the event we are seeking despite interference from stronger competitors, and we can stop ourselves from thinking about unwanted memories. Given these parallels between motor behavior and retrieval, response override mechanisms may be recruited to control unwanted memories. If so, we should find evidence for inhibitory control in memory situations likely to involve response override.

By our view, strong evidence for these parallels exists. In support of this, I briefly review evidence for inhibition in memory selection and in memory stopping. Memory selection is required when our goal is to recall an event or fact from memory in the face of interference from related traces that become activated by cues guiding retrieval. The need to stop retrieval arises when we confront a cue and wish to prevent an associated memory from entering awareness. In both cases, attempts to limit the influence of distracting memories have been found to impair later retention, highlighting an important link between forgetting and the control of retrieval.

Selective Retrieval and Retrieval-Induced Forgetting

The need to select a weaker response to a stimulus in the face of interference from a prepotent competitor finds a parallel in memory in the situation of selective retrieval. Here, the aim is to recall a target memory when given one or more cues. Typically, a cue will be associated with other memories as well—and some of those other memories may be more associated to the cue than is the target item. It is well known that when multiple traces are associated to the same cue, they compete for access to consciousness (see Anderson & Neely, 1996; Postman, 1971, for reviews). This form of competition presents a problem of control because the cue cannot be relied upon to access the target—in fact, the presence of a strong competitor could perpetually divert us from that target. If inhibitory control is recruited to override prepotent responses, then inhibition might also be used to override prepotent memories. To the extent that inhibition persists, situations demanding the selective retrieval of a target should induce lasting memory impairment on competitors. Thus, the act of remembering should cause forgetting of related memories.

Over the last decade, my colleagues and I have explored this prediction with a procedure that we refer to as the retrieval practice paradigm (Anderson, Bjork, & Bjork, 1994). In the typical study, subjects encode lists of category-exemplar pairs (e.g., fruit – orange, drink – scotch, fruit – banana). They then perform retrieval practice on half of the exemplars from half of the categories by completing cued stem recall tests (e.g., fruit-or_____). Each practiced item is tested several times to increase the effect of retrieval practice on related items. After a delay, subjects are tested on

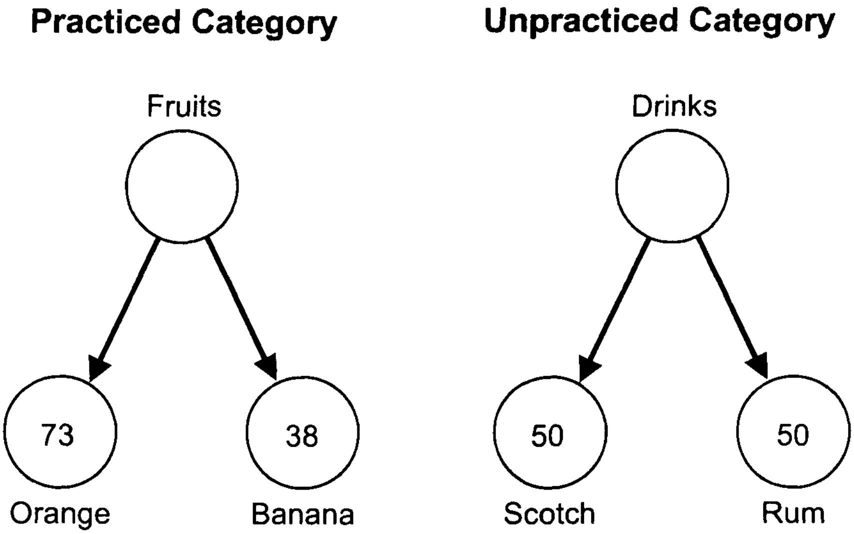

Fig. 2. A typical within-category retrieval-induced forgetting study, as done by Anderson et al. (1994). The example illustrates two items from each of two categories that subjects have studied (6 items are usually studied in 8 categories). In this example, subjects have performed retrieval practice on Fruits Orange, but not on Fruits Banana (unpracticed competitor) or any members from the Drinks category (an unpracticed baseline category). As shown here, practice typically facilitates recall of the practiced item, and impairs recall of the unpracticed competitor, relative to performance in baseline categories.

all studied exemplars. Performance on this category cued recall test can be measured for three item types: practiced items (e.g., orange), unpracticed items from the practiced categories (e.g., banana), and unpracticed baseline items from unpracticed categories (e.g., scotch). Figure 2 illustrates typical findings. Not surprisingly, recall of the practiced exemplars was improved relative to performance on baseline items. More importantly, recall for the unpracticed exemplars from the practiced categories (e.g., banana) was worse than that for the items from baseline categories (e.g., drinks). Thus, remembering some items during retrieval practice led subjects to forget related items on a delayed test. We refer to this finding as *retrieval-induced forgetting* (Anderson et al., 1994) to highlight the central role that retrieval plays in generating the effect. Retrieval-induced forgetting is consistent with the view that inhibitory control is recruited to combat interference during retrieval, with inhibition manifesting as recall impairment for competitors on the final test.

Although the basic finding of retrieval-induced forgetting is compatible with inhibition, other mechanisms can explain this effect as well, including McGeoch's (1942) classical response competition theory of interference. According to this theory, the likelihood of recalling a target should decrease either when a new response gets associated to the cue used to retrieve it, or when an existing alternative response is strengthened. In either case, the target will suffer increased competition from the alternative response. These competitive dynamics have become formalized in several memory theories that posit relative strength rules of retrieval (e.g., Raaijmakers & Shiffrin, 1981; J.R. Anderson, 1983). In these models, the probability of recalling a target is determined by that item's association to a cue, relative to the strengths of association of all items related to that cue. When an alternative response is strengthened, say by retrieval practice, the relative strength of all nonpracticed items declines. Later, when the subject tries to recall the target, the strengthened competitor will have a retrieval advantage, leading it to intrude so persistently that the subject abandons efforts to recall the unpracticed exemplars (see also, Rundus, 1973).

This approach does not require inhibition; rather, practiced items become so strongly linked to the practice cue that they block other exemplars. This account is plausible, given the strengthening that practiced items enjoy (but see the later section in this chapter on properties of retrieval-induced forgetting). Other mechanisms may also contribute to retrieval-induced forgetting. For example, retrieval practice may damage the association linking the category to the affected exemplar or instead may alter the meaning of the practiced category cue (e.g., by biasing "*Fruits*" towards '*Citrus fruits*") so that the category label is no longer a functional cue for retrieving the unpracticed competitor. All of these mechanisms have been proposed as theories of interference (for a review of noninhibitory sources of impairment, see Anderson & Bjork, 1994). Although it might seem difficult to distinguish these alternatives, focused empirical research has yielded evidence for properties of retrieval-induced forgetting that favor the inhibition view.

Properties of Retrieval-Induced Forgetting

Work on retrieval-induced forgetting has revealed properties that uniquely support the inhibitory control hypothesis, and that suggest that alternative strength-based models may not be correct (see Anderson, 2003, for a review). First, several findings demonstrate that strengthening practiced items does little to impair the recall of related competitors provided that all sources of retrieval-induced forgetting are eliminated from the strengthening process and from the measurement of impairment. For instance, retrieval-induced forgetting appears to be *recall-specific*: Retrieval practice impairs the delayed recall of competing items, but the same number of repeated study exposures does not (provided that output interference is controlled on the final test), even though the two practice procedures strengthen practiced items to the same degree. The fact that strengthening can occur with little associated impairment suggests that retrieval practice, not strengthening, is responsible for the effect. Consistent with this, when retrieval practice is performed, the amount of impairment often has no relation to the amount of strengthening observed on practiced items—that is, retrieval-induced forgetting appears to be *strength-independent.*

Impairment does appear to be *interference-dependent*, however: Whether retrieval practice impairs a related item depends on whether the item causes interference during retrieval practice. So, for instance, high frequency exemplars of categories suffer retrieval-induced forgetting whereas low frequency exemplars do not; similarly, the dominant meanings of asymmetric homographs suffer significant retrieval induced forgetting, whereas the subordinate meanings do not. Interference-dependent impairment is exactly what one would expect if inhibitory control is recruited to override retrieval of distracting competitors.

Finally, retrieval-induced forgetting exhibits a crucial theoretical property that is difficult for traditional associative interference accounts to explain: *cue independence.* Cue independence refers to the tendency for retrieval-induced forgetting to generalize to novel cues other than those used to perform retrieval practice. Retrieval practice on Fruit-Orange not only impairs the later recall of Banana when it is tested with the cue Fruit, but also when it is tested with a novel, independent cue such as Monkey B____. These findings argue against interpretations of retrieval-induced forgetting such as associative blocking or cue change, which posit mechanisms that are specific to the cues guiding retrieval practice. These findings are, however, consistent with the idea that competing memories themselves are suppressed by an inhibitory process in order to retrieve the retrieval practice target.

Taken together, the foregoing properties indicate that the impairment underlying retrieval-induced forgetting is unlikely to be produced by traditional associative interference mechanisms. Rather, it is likely to reflect the action of an inhibitory control process acting to override unwanted retrievals of competitors in memory, helping to achieve selective memory retrieval. This supports the view that selective memory retrieval may be regarded as a special case of response override arising in long-term memory retrieval.

Stopping Memory Retrieval

Response override is also involved when we need to stop a response. In retrieval, the ability to stop could prove useful in preventing a memory from entering consciousness. We sometimes confront reminders of things that we would prefer not to think about: The sight of a car may remind us of an accident we had, or of a former significant other who drove that type of car; or the sight of the World Trade Center in a movie may lead us to stop the natural progression from cues to memories. Other times, we may wish to focus on a thought without letting our mind wander. Can inhibitory mechanisms be engaged to serve these goals?

Anderson and Green (2001) looked at this issue by examining how stopping retrieval affected the memories that were to be retrieved. To study this, they developed a procedure modeled after the widely used Go/No-Go task, which has been used to measure the ability to stop a prepotent motor response and to study its neural basis in humans (e.g., Casey et al., 1997; Garavan et al., 1999) and monkeys (e.g., Sakagami & Niki, 1994). In one version of the this task, letters are presented one at a time and subjects press a button as quickly as possible whenever they see a letter, *except* when the letter is an X. When they see an X, they are supposed to avoid pressing the button. The majority of trials require a button press so that, when an X occurs, subjects have difficulty withholding their response. The ability to withhold the response is taken as a measure of inhibitory control.

To explore whether people can stop retrieval, Anderson and Green (2001) adapted the go/no-go task to create the *think/no-think paradigm*. In this procedure, subjects studied pairs of weakly related words (e.g., flag – sword, ordeal – roach) and were then trained to provide the second word (e.g., roach; hereafter referred to as the response word) whenever they were given the first word as a cue (e.g., ordeal). Subjects then entered the think/no-think phase, which required them to exert control over retrieval. For most of the trials, the task was the same as it had been during training—to recall and say aloud the associated word as quickly as possible at the sight of its cue. For certain cues, however, subjects were admonished to avoid thinking of the response. It was emphasized that it was not enough to avoid *saying* the response word—it was crucial to prevent the memory from entering *conscious awareness* at all. Thus, subjects had to override not only a vocal response, but also the cognitive act of retrieval.

Could subjects recruit inhibitory control mechanisms to stop the memory from entering consciousness?

Of course, Anderson and Green could not directly measure whether subjects controlled consciousness. However, if inhibitory control was recruited, later recall of the excluded memory should be impaired. To examine this, immediately after the think/no-think phase, subjects were given the cues for all of the pairs, and asked to recall the response for each. As predicted, forgetting occurred: Response words that subjects excluded from awareness were impaired compared to baseline pairs they had studied initially but had not seen during the think/no-think phase. The more often subjects tried to stop retrieval, the worse recall became (see Figure 3a). Interestingly, avoided words were harder to recall even though subjects had seen as many as *16 reminders* (i.e., cues) during the think/no-think phase. Normally, reminders facilitate memory, much as they did for the items to which subjects continued to respond (Figure 3a).

Anderson and Green (2001) further established that this impairment was cue independent, echoing the results of Anderson and Spellman (1995): Forgetting occurred regardless of whether subjects were tested with the studied cue word (e.g., ordeal) or with a novel cue never studied in the experiment (e.g., insect r____ for roach; Figure 3b). This argues that the forgetting is not caused solely by associative interference; rather, impairment reflects suppression of the excluded memory itself. In a control experiment, subjects were merely asked to avoid saying the response out loud and all mention of preventing it from entering awareness was eliminated. No inhibition was observed, indicating that the recall deficits were not merely due to suppression of the vocal response for avoided words. These results isolate forgetting in the think/no-think paradigm to processes directed at keeping the unwanted memory out of awareness, and demonstrate that this cognitive act has persisting consequences for the avoided memories.

The impaired memory observed by Anderson and Green (2001) suggests that inhibitory control mechanisms may be recruited to regulate awareness of intrusive memories. In particular, whenever the environment presents unavoidable reminders to something that we would prefer not to think about, people may resort to controlling their memories instead. The end result may be impaired memory for the things that people avoid thinking about. This suggests that the think/no-think paradigm of Anderson and Green (2001) may provide a useful laboratory model of the voluntary form of repression (suppression) proposed by Freud (1966). If so, results from this paradigm and other related paradigms such as the directed forgetting procedure may have implications for understanding clinical phenomenon relating to motivated forgetting (Anderson, 2001; Anderson & Green,

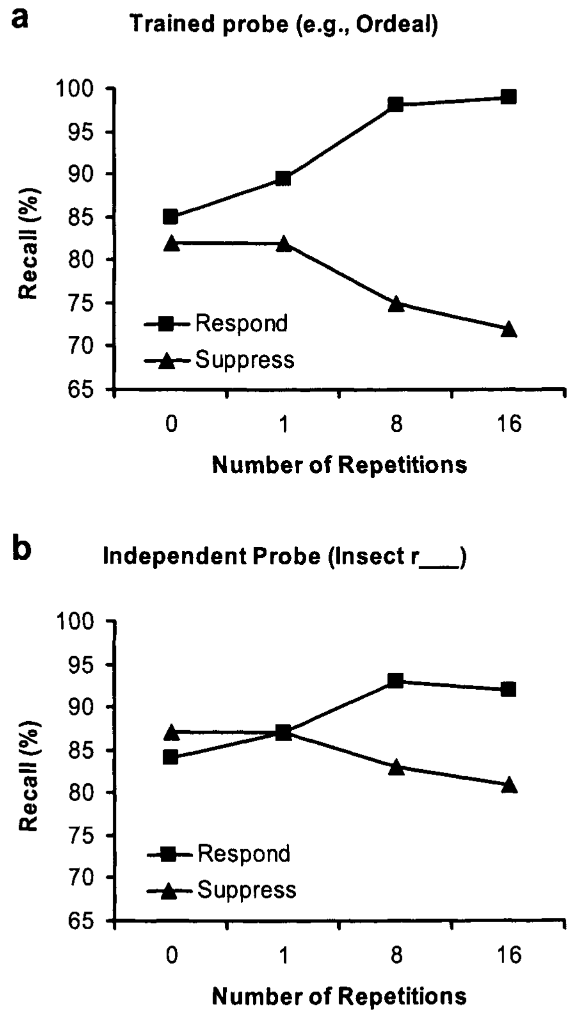

Fig. 3. Final recall performance in Experiment 1 of Anderson and Green (2001) using the think/no-think procedure. The plot represents the percentage of items that subjects recalled on the final recall test as a function of the number of times that they suppressed the item (suppress), or tried to recall it (respond). The top panel (a) represents final recall performance when tested with the originally trained retrieval cue (i.e., the "Trained probe"), whereas the bottom panel (b) represents final recall performance when tested with a novel, independent, extralist category cue.

2001; Bjork et al., 1998; Conway et al., 2000; Deprince & Freyd, 2001; Myers, Brewin, & Power, 1998; see Golding & MacLeod, 1998, for a review of directed forgetting). More broadly, these findings may be related to cognitive situations in which people must "deselect" unwanted aspects of the representation of a stimulus to attend to task relevant attributes (see, e.g., Rajaram, Srinivas, & Travers, 2001; Rajaram, this volume; see also, Humphreys, this volume).

Neural Systems Underlying Voluntary Memory Suppression

The foregoing work on selective retrieval and retrieval stopping indicates functional parallels between controlling retrieval and overriding prepotent responses. This suggests the intriguing possibility that the ability to control unwanted memories may in part rest on neural systems essential for controlling overt behavior. More direct evidence for this relation might be observed if more were known about the anatomical systems that support memory control. Recently, we have used neuroimaging to identify the neural systems underlying this ability. If memory control and response override are related, one might expect stopping memory retrieval to recruit neural systems known to be involved in overriding prepotent responses to control structures involved in memory.

Research on the neural basis of executive control and declarative memory indicates that at least two brain regions may play important roles in the neurobiological basis of memory control: the hippocampus and the lateral prefrontal cortex. The hippocampus is essential for declarative memory formation (Squire, 1992), and increased hippocampal activation is associated with the subjective experience of consciously recollecting a recent event (e.g., Eldridge et al., 2002). Memory suppression requires people to stop retrieval to prevent conscious recollection. Lateral prefrontal cortex is involved in overriding prepotent motor responses (e.g., Aron et al., 2003; Garavan et al., 2002; Menon et al., 2001), switching task set, and combating interference in a range of cognitive tasks (e.g., Aron et al., 2004; Knight et al., 1999; Shimamura, 2000). We hypothesized, therefore, that people suppress consciousness of unwanted memories by recruiting lateral prefrontal cortex to disengage hippocampal processing that supports recollection.

Anderson et al. (2004) recently examined this fronto-hippocampal hypothesis using the think/no-think procedure. Subjects first learned pairs of words. They then received trials in which they were given the first member of a word pair and asked (if the word appeared in green) to think of its corresponding response (Respond condition) or (if the word appeared in red) to suppress awareness of the response (Suppression condition). Subjects performed this task while being scanned in an event-related functional magnetic imaging design. After this phase was over, scanning ended, and memory was tested for all of the word pairs subjects had studied. Replicating prior work, subjects recalled significantly fewer suppression than baseline items, showing that suppression had occurred.

To examine the neural systems underlying suppression, we contrasted activation during Suppression and Respond trials of the think/no-think phase. In both trial types, subjects had been presented with a cue word for 4 seconds that had previously been associated with a response word; the only difference was that the cues presented in red had directed subjects to suppress consciousness of the unwanted memory, whereas those presented in green had directed subjects to recall and maintain the corresponding response. Several remarkable findings were obtained. First, a network of regions was more active during suppression than during active retrieval, including bilateral dorsolateral and ventrolateral prefrontal cortex, and anterior cingulate cortex. This network overlaps strongly with networks involved in motor response suppression tasks (such as go/no-go), even though no motor responses were required. These findings support the possibility that neural systems involved in overriding prepotent responses are recruited to control retrieval. More generally, they indicate that regulating consciousness of unwanted memories is an active process, and is not accomplished by simply failing to engage retrieval mechanisms.

Interestingly, Anderson et al. (2004) also found that suppressing awareness of a memory significantly reduced activation in the hippocampus bilaterally, relative to retrieval. Because activation in the hippocampus has been linked to conscious recollection, this finding suggests that subjects can control awareness of past experiences by strategically disengaging activation in the hippocampal memory system that might otherwise support conscious recollection.

One might wonder to what extent the suppression regions observed in the overall analysis are functionally involved in suppressing unwanted memories. More compelling support for this role could be obtained if it could be shown that these regions predicted later memory suppression effects. We evaluated this by using regression to examine which brain regions predicted individual differences in memory inhibition. Crucially, activation in dorsolateral prefrontal cortex and lateral premotor cortex, regions often observed in go/no-go task performance, predicted subsequent memory impairment for suppression items (Figure 4a). The more activation there was in these regions, the more suppression subjects showed (Figure 4b). We further showed that activation in the hippocampus predicted later memory failures for suppressed items and that these variations

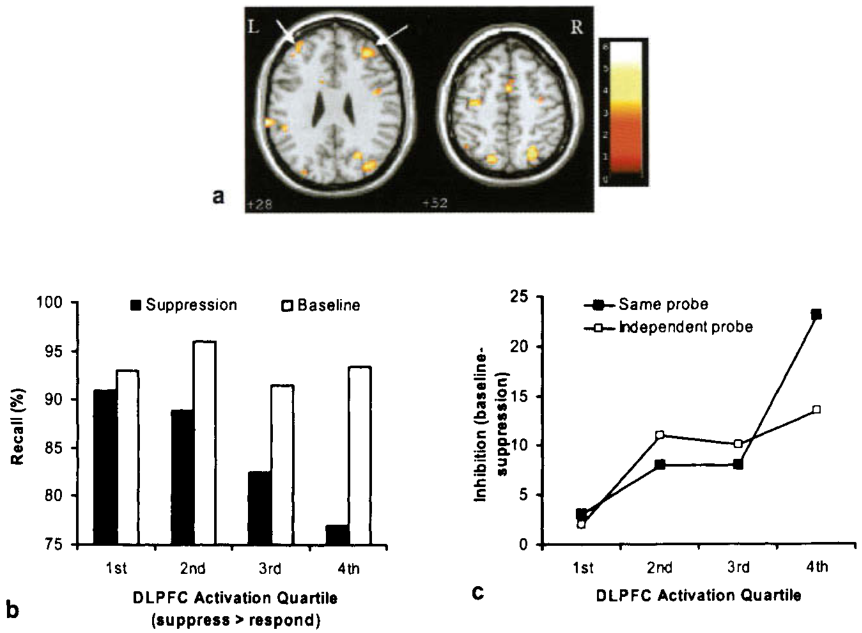

Fig. 4. Relation of suppression-related activations to memory inhibition. (a) Regions for which activation during suppression trials predicted differences in below-baseline inhibition (n = 24). White arrows highlight DLPFC regions from the regression analysis that also predict hippocampal activity for suppression items. (b) Memory inhibition effects for four subject groups matched for counterbalancing manipulations, differing in degree of activation in right DLPFC. Note that increasing activation in DLPFC predicts reduced suppression performance, but leaves baseline performance unaffected. (c) Memory inhibition effects (Baseline – Suppression) in four DLPFC groups, separated by test type.

were correlated with activation in the dorsolateral prefrontal cortex. These findings suggest that dorsolateral prefrontal cortex interacted with medial-temporal lobe structures to attenuate activity, reducing recollection and disrupting retention.

This work provides a strong indication that some of the neural systems involved in overriding prepotent responses may also be recruited to terminate internal actions such as retrieval. Such systems appear to be targeted at medial-temporal regions that support declarative memory rather than motor representations. Because ideas and memories are brought into consciousness by retrieval, the capacity to stop retrieval provides a specific cognitive and neurobiological foundation for how human beings regulate consciousness of unwanted memories. This work further supplies a model for how motivated forgetting occurs that may be applicable to understanding the adaptation of memory in the face of traumatic experiences. By integrating this model with insights derived from other empirical approaches, we can more fully characterize the variety of ways in which people may regulate awareness of unwanted memories.

Forgetting Unwanted Memories: A Comparison of Methods

So far in this chapter, I have focused on research using the retrieval practice and think/no-think paradigms. Other paradigms have been used to study the inhibition of unwanted memories, however. In this final section, I will discuss the relation of the current procedures to an important method used to study intentional forgetting: Directed forgetting. By considering the relation between these paradigms, I hope to encourage direct comparison of the methods, and foster principled theoretical development. I begin with a brief review of different methods used to study directed forgetting, along with some preliminary considerations of the nature of inhibitory effects in directed forgetting studies. I then offer a simple framework within which the paradigms for studying inhibition effects may be considered.

Directed Forgetting: the Phenomenon and its Interpretations

The term *directed forgetting* refers to impaired memory arising from an instruction to forget the unwanted material. Such impaired memory has been readily observed in two experimental procedures, known as *item method* and *list method* directed forgetting (see Sheard & MacLeod, this volume; see also Golding & MacLeod, 1998). In the item method, subjects typically view a series of words, each followed by an instruction cuing them to remember the item for a later test, or to forget it. After all of the words have been presented, memory is tested with either a recall or a recognition test. The item-by-item instruction manipulation yields a sizeable recall deficit for "forget" items relative to remember items that occurs on both recall and recognition tests. Directed forgetting in studies using the item method is thought to reflect selective rehearsal of the to-be-studied words. For instance, subjects may rehearse words shallowly (e.g., by subvocal repetition) until they receive the cue, at which point they either (a) stop rehearsing the word in the case of the forget instruction, or (b) elaboratively encode the word in the case of the remember condition. This view is consistent with the impaired performance of forget items on recognition tests. If correct, this interpretation suggests that item method directed forgetting is more properly regarded as an encoding effect, rather than as evidence for inhibition.

The list method differs from the item method mainly according to when the instruction to forget is presented. In the list method, subjects receive an instruction to forget or to remember the studied items only after a long list (typically 10-20 words) has been encoded. The instruction, furthermore, is a surprise and so subjects are likely (prior to the instruction) to extend their best efforts to encode the words. This feature of the procedure is thought significant because it makes it less likely that differential encoding of first-list items could underlie recall deficits arising from the forget instruction (however, see Sheard & MacLeod, current volume). After the forget or remember instruction is given, subjects study a second list. Once both lists have been presented, memory is tested. The test may require recall of the first list, the second list, or both lists.

The list method often yields three effects that typify this form of directed forgetting: (a) impaired recall for the first list of items when subjects are instructed to forget the first list, compared to when they are to remember it (i.e., directed forgetting *costs*); (b) improved recall for the second list of words when subjects are instructed to forget the first list, relative to when they are to remember the first list (i.e., directed forgetting *benefits*); and (c) superior memory for second-list words compared to first-list words in the forget-instructed group. These effects are generally restricted to recall tests, with little effect observed in recognition.

This pattern has led investigators to attribute list method directed forgetting to retrieval inhibition. By this view, items on the first list are inhibited by the instruction to forget, but remain available in memory, as evidenced by intact performance on recognition tests. If this analysis is correct, then list method directed forgetting is more likely to have mechanisms in common with the retrieval-practice and think/no-think procedures than would item method directed forgetting. However, even with the list method, several restrictions should be placed on what constitutes evidence for directed forgetting. Two of these are discussed next.

Comparing Recall Performance Across Lists 1 and 2 is Not a Good Measure of Directed Forgetting

Many directed forgetting studies simplify the design by eliminating the control group in which subjects are instructed to remember the first list before proceeding to the second list. These studies have one primary condition—the forget group—and recall performance is compared for items on the first (the forget list) and second (the remember) lists. The difference in recall across these lists is taken as a metric of directed forgetting because the two lists are believed to differ only by the instruction given after the list is encoded. Superior recall of second list items is thought to reflect a mixture of the costs on first list items and the benefits on second list items.

The method of comparing list-1 and list-2 recall is fraught with difficulties, and should not be taken as retrieval inhibition. The assumption that the two lists differ only by the nature of the instruction is not correct, leading many other factors to get mixed into the estimate of inhibition. Several such differences exist. First, the second list is studied more recently, and this difference surely confers a recall advantage on the second list that has little to do with directed forgetting. Second, by the time the second list is presented, subjects have been exposed to the task, and to the nature of the stimuli that they are likely to receive. This difference may alter subjects' approach to the second list, as suggested by classic research in verbal learning on warm-up increment and learning-to-learn (Postman, 1971). Thus, recall may improve on the second list because subjects simply get into the rhythm of the task, or, alternatively, develop more well-tuned strategies for encoding items—strategies that may be qualitatively different from those used in the first list. Finally, the second list may cause retroactive interference, even in the absence of any instruction to forget the first list.

Collectively, these variations across list-1 and list-2 are confounding variables that compromise interpretation of differences in recall arising from the forget instruction, and so these differences should not be taken as evidence for directed forgetting. These confounds are avoided when directed forgetting is estimated by comparing the first list in the forget group to a control group instructed to remember those same items. I view this list-1 comparison (i.e., the cost comparison) as the only pure measure of retrieval inhibition, to the extent that such a process contributes to directed forgetting (see Sheard & MacLeod, this volume, for a discussion of alternative mechanisms that may also contribute to list-1 costs).

Studies of Directed Forgetting That Do Not Control Output Order Conflate Directed Forgetting with Output Interference

Even when a study estimates directed forgetting with a cost comparison, differences do not necessarily reflect the action of the forget cue. Differences may instead reflect differential output interference across the forget and remember conditions. Consider a directed forgetting experiment in which subjects are asked on the final test to recall both the first and second lists in any order. If the recall of list-1 items is worse after a forget instruction than after a remember instruction, does this mean that list-1 was suppressed as a result of the forget instruction? Not necessarily. The forget subjects may have remembered fewer list-1 items because they were biased to recall list-2 items earlier.

Such a bias could arise in several ways. First, because a forget instruction on list-1 typically improves recall for list-2 items, this enhanced accessibility (relative to the remember group) may lead list-2 items to be recalled earlier in the forget group. Enhanced recall of list-2 items might arise because they are better encoded when subjects do not have to try to remember list-1 items as well. Second, the instruction to forget the first list may bias subjects to begin their recall with list-2 items, merely because they are implicitly deemed more important. Subjects in the remember group are responsible for remembering both lists and would have neither of these biases. As such, the groups may differ in the propensity to recall list-2 items early, yielding an output order bias against list-1 items that could produce recall deficits in the forget group. Because output interference is considered a form of retrieval-induced forgetting, this method of measuring directed forgetting mixes retrieval-induced forgetting and "true" directed forgetting effects.

There are several easy solutions to the foregoing problem. Subjects may be directed to recall only the list-1 items in both the forget and the remember group or, instead, to recall list-1 items followed by list-2. Directing subjects to recall first list items right away eliminates output interference from second list items and matches this factor in the remember and forget groups. Thus, any remaining differences should reflect the forget instruction and not output interference. It should be noted, however, that although estimating directed forgetting with this method provides a more theoretically focused measure of retrieval inhibition, the less controlled method provides different information. In real life settings, the total negative impact of an effort to forget may be determined by the "true" inhibitory effect of directed forgetting, compounded by retrieval biases and the accumulating output interference effects they produce. Nevertheless, when the goal is to isolate properties of the inhibition mechanism, the more focused procedure for estimating inhibition should be used.

Views on the Relation of Directed Forgetting to the Current Phenomena

Given the preceding constraints on evidence, the relation between directed forgetting, retrieval-induced forgetting, and memory impairment produced by the think/no-think procedure can be understood in several ways. Some have argued for a distinction between controlled and automatic forms of inhibition. I will discuss this perspective, and some of the evidence thought to support it. I will then propose an alternative view that rests on two factors: the intention to forget, and the level of representation affected by inhibition. I will end by considering the implications of this framework for proposals concerning the mechanisms underlying directed forgetting.

Controlled versus Automatic Inhibition

Some have argued that retrieval-induced forgetting and directed forgetting differ in the level of executive control involved in producing inhibition (e.g., Conway & Fthenaki, 2003). Several considerations motivate this proposal. First, directed forgetting requires an intentional effort to forget, whereas retrieval-induced forgetting does not. Because goal directed cognition generally requires cognitive control, explicit instructions to forget should place demands on controlled attention. Second, some evidence suggests that directed forgetting requires attention to be performed properly. Dividing attention during the encoding of the second list disrupts directed forgetting on the first list (Conway, Harries, Noyes, Racsma'ny, & Frankish, 2000). Directed forgetting also appears to be diminished in populations thought to suffer deficits in executive control, such as in the elderly (Zacks, Radvansky, & Hasher, 1996), young children (Harnishfeger & Pope, 1996), and frontal-lobe damaged patients (Conway & Fthenaki, 2003). Together, these findings suggest that directed forgetting requires controlled inhibition. Although these arguments have not been formally extended to the think/no-think procedure, the fact that this procedure instructs subjects to exclude a memory from awareness would seem, by the same logic, to require controlled processing that ultimately leads to inhibition.

Retrieval-induced forgetting, by contrast, might seem to require less control. In this procedure, no instruction to forget is given; rather, forgetting is a by-product of retrieving related material. Because these effects are unintentional, they may be produced by automatic processes. Automatic inhibition mechanisms can certainly be envisioned for retrieval-induced forgetting: Retrieving targets may inhibit competitors by means of automatic lateral inhibitory connections, for example. Consistent with the automaticity view, several studies have found intact retrieval-induced forgetting in populations thought to be deficient in executive control. Moulin, Perfect, Conway, North, Jones, and James (2002) found that older adults with and without Alzheimer's disease showed robust retrieval-induced forgetting, contrary to what these authors expected if these populations had deficits in controlled inhibition. Conway and Fthenaki (2003) found that frontal patients showed diminished directed forgetting; however, frontal patients exhibited significant, though reduced retrieval-induced forgetting. Because the prefrontal cortex is thought to support executive control, these findings appear compatible with the view that retrieval-induced forgetting is produced by a more automatic form of inhibition.

Although the foregoing view is plausible, there are problems with the arguments for it. The major difficulty arises from the fact that all of the preceding studies used a final memory test that provided subjects with the same cue used to perform retrieval practice. For instance, when subjects performed retrieval practice on several fruits, later recall was assessed with "Fruits" as the cue rather than a separate cue designed to test the accessibility of the inhibited items. Because of this, the measure of retrieval-induced forgetting mixes impairment arising from suppression with interference from the practiced items. Thus, when subjects recall Fruits, they may perseveratively recall the stronger practiced items, blocking access to competitors.

These two sources of impairment—blocking and suppression—should be differentially affected by attentional deficits (and also by dividing attention). For example, deficient attentional inhibition should reduce the contribution of suppression to retrieval-induced forgetting, decreasing the effect. In contrast, that same deficiency should increase vulnerability to interference from the practiced items, exaggerating the effect. Thus, even if frontal lobe or Alzheimer's patients had no capacity for attentional inhibition, they should show sizeable retrieval-induced forgetting to the extent that these deficits render subjects unable to combat interference from practiced competitors on the final test. Indeed, this vulnerability to interference (the tendency for frontal patients to perseverate strong responses) forms the basis for the inhibitory deficit hypothesis of frontal lobe function. Thus, no conclusions can be inferred about inhibitory deficits when the independent probe method is not used. There is little reason, at present, to conclude that retrieval-induced forgetting does not require cognitive control.

Independent of these empirical arguments, one may question whether the lack of intention to forget competing items in the retrieval-induced forgetting procedure should be equated with a lack of cognitive control. Although this seems plausible at first, I will argue in the next section that such a linkage is entirely unnecessary and perhaps incorrect.

The Flexible Control Hypothesis: An Alternative Framework

Retrieval-induced forgetting, impairment in the think/no-think paradigm, and directed forgetting may not stem from different types of inhibition varying in automaticity. Rather, they may reflect a common inhibitory process that is flexible in two important ways. First, it seems plausible that the inhibition mechanism may be *goal general*—that is, it can be recruited for different cognitive goals, including memory retrieval, working memory maintenance, selective attention, avoidance of unwanted thoughts, and intentional forgetting. The idea that inhibition is goal general is implicit in many proposals concerning inhibition as a controlled process. Nevertheless, it is worth emphasizing here, because it provides an important proposition necessary to our account of the relations between these phenomena. Second, the inhibition mechanism may be *representation general*—that is, once recruited, it can be targeted at different types of representation. Inhibition can be targeted at episodic or semantic memories, and at memories varying in content. Importantly, in the current proposal, inhibition can be targeted at different levels of representation. Inhibition may be targeted at individual items within a context, or at a global contextual representation. Here again, this flexibility is implicit in the notion of controlled inhibition. The idea that inhibition can be targeted at individual items or contexts will be featured in our account of the differences between inhibitory phenomena. These considerations suggest that it may be worthwhile to evaluate the ways in which memory inhibition tasks differ in their goals and in the targets of inhibition. We consider each of these dimensions in turn.

Differences in Goals, Not in Control

All of the tasks discussed in this chapter differ in the goals for which inhibition is recruited. In retrieval-induced forgetting, the goal is to recall target items, given (in many cases) a category plus a letter stem cue. No instruction is given to forget competing exemplars, nor are competitors mentioned. Whatever inhibition occurs thus does not arise from an explicit goal to forget competitors, but rather from a goal to retrieve target items. In directed forgetting, however, the putative inhibition process is initiated by the "forget" instruction itself, although effective inhibition is also believed to rely on encoding new information in a second list. Whatever inhibition occurs on to-be-forgotten items is tied to an explicit goal to forget that makes mention not of individual items per se, but of the entire first list. Finally, in the think/no-think procedure, inhibition takes place when subjects exclude the unwanted memory from consciousness. No instruction to forget is given, though the to-be-inhibited item is mentioned because the task is to exclude that item from awareness. Whatever inhibition accrues arises from a goal that concerns the target, though the goal is not to forget.

The preceding analysis illustrates how inhibition may be recruited in support of different goals. One might wonder, however, whether the inhibition involved in each case is the same. According to the controlled/automatic distinction, for example, the inhibition underlying directed forgetting and effects in the think/no-think paradigm differs qualitatively from the form of inhibition at work in retrieval-induced forgetting. I believe, however, that this proposal confuses two similar, though separable dimensions: the explicitness of the goal to forget, and the presence of executive control. According to the flexible inhibition hypothesis, controlled inhibition may be recruited in service of our goals, regardless of whether these goals make reference to forgetting, as long as there is a control problem. For instance, the retrieval-practice paradigm makes no reference to forgetting, but isolating the target during retrieval practice may require cognitive control to push distracting competitors out of mind. Similarly, the goal of keeping an unwanted memory out of awareness makes no reference to forgetting; nevertheless, the cue to which subjects attend activates the memory subjects are avoiding, requiring inhibitory control. Thus, although instructing subjects to forget items may entail controlled inhibition, the lack of intention in retrieval-induced forgetting does not imply an absence or even a reduction of controlled inhibition. The working assumption is that all of the paradigms discussed here (to the extent that each involves inhibition) make use of a common controlled inhibition process.

Differences in Representational Target of Inhibition

Inhibition may also be targeted at different types and levels of representation. In directed forgetting, the instruction to forget does not make reference to individual items, but rather to the entire first list. Although such an instruction might be achieved in many ways, inhibition may target the list-1 context rather than individual items. By this view, each item on the first list is encoded with the list-1 context. The context could be regarded as a discrete "list" concept or a collection of features that permits discrimination and source recollection. If the contextual representation were to be suppressed, it could reduce the accessibility of all items in this list, even though no individual item was suppressed. If subjects construct a new context representation for the second list, proactive interference from list-1 should be minimized during the encoding of list-2. Furthermore, list-1 recall should suffer if subjects use a contextual representation at test that is favorable to list-2 items. Thus, the immediate cause of list-1 impairment may be the use of inappropriate contextual cues, although this ultimately may arise from suppression of the list-1 context.

The retrieval-practice paradigm presents a situation more likely to favor the suppression of individual items rather than of the global list context. Because the retrieval practice targets are to be retrieved from the original study list context, suppressing that context would be an ineffective solution to combating interference from related items on that list. Even if the first list context were suppressed, presenting a category name as a retrieval practice cue would prompt interference from other studied exemplars, based purely on priming. Thus, to reduce interference, inhibition must be recruited on a trial-by-trial basis, in response to intrusions of related items. If so, inhibition should affect individual items, rather than the global context (though some effects of contextual shift between the list-1 and retrieval practice phases should also be considered). Similar arguments can be made about the inhibition that arises in the think/no-think paradigm. Thus, inhibition in the directed forgetting paradigm may influence a different level of representation than is affected in the retrieval practice and think/no-think paradigms, even if a common inhibition mechanism is involved.

The functional properties of retrieval-induced forgetting and of directed forgetting support the distinction between context-level and item-level inhibition. Research on retrieval-induced forgetting suggests an item-level effect. That competitors are recalled worse than baseline items from the same study list indicates that the effect cannot be a general suppression of the study-list context. Moreover, the generalization of impairment to novel cues and the observation of impairment on cued recall, recognition (e.g., Hicks & Starns, 2004), and lexical decision tests (Veling & van Knippenberg, 2004) all support the claim that accessibility of individual items has been diminished.

Research on directed forgetting, by contrast, indicates that forget instructions impair recollection, without disrupting the items themselves. For example, the same directed forgetting procedure that produces forgetting in free recall yields priming of inhibited items on indirect tests (e.g., Basden, Basden, & Gargano, 1993). When subjects perform a fame-judgment task for a list of names, names that appeared on a to-be-forgotten list are more likely to be judged famous than names in a to-be-remembered list, even when subjects are admonished not to judge studied items as famous (Bjork & Bjork, 2003). These findings suggest that items impaired by directed forgetting remain primed. These items are impaired, however, when they have to be accessed from the temporal context, an impairment that can be alleviated when the context is provided. Subjects exhibit impaired source memory for list-1 items even when item recognition is intact (e.g., Geiselman, Bjork, & Fishman, 1983). However, when some items from a list are given as cues for the remaining items (Goernert & Larson, 1994), or when some items are re-exposed in a recognition test (Bjork, Bjork, & Glenberg, 1973), accessibility of list-1 item improves, as indicated by diminished costs and diminished benefits, respectively. Finally, when directed forgetting instructions are replaced by instructions to induce a new mental context at the outset of a second list, many of the characteristics of directed forgetting are created (Sahakyan & Kelley, 2002). These findings indicate that list method directed forgetting operates on context rather than on items (see also Kimball & Bjork, 2002, for relevant evidence). Although this has been interpreted as evidence against inhibition (Sahakyan & Kelley, 2002), the context shift account is consistent with inhibition at a different level of representation.

Categorizing Inhibition Tasks by Goal and Target

The preceding analysis suggests that categorizing tasks by goal and by the target may provide a useful way of viewing the relations among paradigms. Figure 5 illustrates one organization of tasks along these dimensions. Rows in this chart represent goals for which inhibition may be recruited, ordered by the degree to which subjects possess an intention to forget. Columns represent tasks that differ by the representation affected, with tasks that target items and contexts represented in the left and right columns, respectively. In this chart, retrieval-induced forgetting is unintentional and affects items, whereas directed forgetting is intentional and affects the list-level (see Kimball & Bjork, 2002, for related arguments). Forgetting in the think/no-think procedure, by contrast, has an intermediate degree of intention. Subjects are asked to exclude the unwanted memory from consciousness. The instructions make no reference to forgetting, however, and are ambiguous from the subjects' point of view. Some subjects may interpret the directions as instructions to forget, whereas others may interpret them as instructions to keep the item out of awareness momentarily. The think/no-think procedure also clearly affects individual items.

This scheme achieves several functions. First, it permits categorization of inhibition tasks, highlighting ones that may have similar properties. For example, part-set cuing inhibition and output interference are cases in which inhibition (if involved) leads to unintentional forgetting. Both tasks also affect item representations in most studies. These forms of impairment therefore might have similar properties, if their main features are captured by the dimensions under discussion. Second, the scheme encourages

	Locus of Effect	
Degree of Intentionality	Item Level	Context Level
Low	Retrieval Induced Forgetting Part Set Cuing	Context Switch Sahakyan & Kelley (2002)
Intermediate	Think/No Think Proactive Interference	Retroactive Interference
High	?	List Method Directed Forgetting

Fig. 5. A chart categorizing different tasks thought to involve inhibition, according to two dimensions: the level of representation at which inhibition acts (individual items, list context), and the extent to which subjects have an explicit intention to forget a memory. Some tasks (e.g., retroactive interference) are difficult to categorize neatly, because they may have multiple effects contributing to them, and some cells are not, as yet, represented by an existing task (e.g., the lower left cell).

reclassification of tasks that might not be thought to require inhibition. For instance, Sahakyan and Kelley's (2002) manipulation of mental context is thought to impair memory without inhibition. However, this task could be unintentional forgetting due to inhibition operating at the level of context. By this view, instructions to shift out of a context and into a new one constitute a requirement to suppress a context and to replace it with a newly retrieved one. This task does not instruct subjects to forget, but may nonetheless recruit inhibition to achieve the shift. If so, one might expect list-method directed forgetting and Sahakyan and Kelley's context shift manipulation to have similar properties. Third, this scheme highlights paradigms that do not exist, suggesting directions for novel research. For example, the bottom left cell—the intentional forgetting paradigm that operates on items—arguably does not exist. One might categorize item method directed forgetting this way, but the item method is thought to reflect differential rehearsal rather than inhibition. Could an inhibitory item level directed forgetting procedure be devised? One might adapt the think/no-think procedure to require subjects to forget the suppression items, rather than to avoid thinking about them. Such a procedure could yield different results, which may be important in understanding the role of intention in suppressing unwanted memories.

Not all tasks will neatly fit into one of the foregoing cells, and depending on how a task is done, a given paradigm may be categorized differently. Consider the A-B, A-D retroactive interference paradigm. On the one hand, forgetting may reflect item-specific suppression of first-list responses (A-B responses). On the other hand, acquiring a second list may suppress the first-list context, inducing a list-wide reduction in performance. Both factors have been hypothesized to play a role in retroactive interference (see Postman, 1971). Retroactive interference is also another example in which the intention to forget is intermediate or a least variable. Subjects may or may not believe that they can forget the first list, and such variations may make RI more or less like directed forgetting.

Part-set cuing can also be characterized in different ways. Some studies using categorized word lists have manipulated the number of category cues provided to subjects on the recall test (rather than providing all of the category names and varying the number of exemplar cues). Robust part-set cuing is found for the remaining categories (see Nickerson, 1984, for a review). However, this type of part-set cuing affects the accessibility of uncued category names themselves, rather than of individual items. Thus, inhibition is acting at a different level of organization (the category list level) than is typically affected by exemplar cuing. Under these circumstances, it is unclear whether part-set cuing should be considered an item- or a list-level phenomenon, as access to whole categories is being affected. That the current framework prompts consideration of these questions suggests it may be useful in encouraging an integrated understanding of memory inhibition paradigms.

Summary

In the beginning of the chapter, selective retrieval and retrieval stopping were presented as two situations that require executive control to suppress unwanted memories. Other perspectives are possible, however. By one view, retrieval-induced forgetting (and other tasks like part-set cuing) differ from directed forgetting and the think/no-think paradigm in their reliance on automatic versus controlled forms of inhibition respectively. Although this is plausible, an alternative view has been proposed here: the flexible control framework. By this view, inhibition can be recruited for many goals, and targeted at different types of representation. Given these types of flexibility, controlled inhibition may be involved in both intentional and incidental forgetting tasks as long as the demand for control is present in each. I have offered a classification of these paradigms, and others, in terms of whether inhibition is intentional, and whether it is targeted at individual items or temporal context. Although it is unclear whether intentionality matters to the characteristics of inhibition, this dimension differentiates the paradigms, and is separable from whether executive control is involved. The available evidence suggests, however, that the level of representation affected is an important dimension that dictates the properties of forgetting. By attending to these dimensions, we may be able to achieve a better understanding of the level of control involved in different inhibition tasks, and of the relation of these phenomena to one another.

Concluding Remarks

The need to control memory pervades daily life, The need is captured vividly by a moment with which we are all familiar. This moment occurs when, by chance, we encounter a cue in our environment that reminds us of an unpleasant past event—a brief flash of experience and feeling that is rapidly followed by an attempt to exclude the unwanted trace from awareness. We, in essence, put up the "mental hand" in an effort to, as we say, "not go there." This form of mental control occurs with striking frequency in mental life, especially following disturbing or traumatic experiences (Dougall, Craig, & Baum, 1999), and can certainly lead one to wish that a memory "deletion" device existed. Despite the prevalence of these experiences and their clear clinical importance, experimental psychology has had surprisingly little to say about how this control is accomplished, and what its limits may be.

In this chapter, I have reviewed our approach to this issue, the empirical evidence that supports it, and the relation of these findings to data obtained in research on directed forgetting. Our central claim is that the capacity to control memory rests on the ability to override unwanted memory retrievals, a function that I claim is rooted in a fundamental ability to override prepotent responses. By this view, the moment when we exclude an unwanted memory from awareness is accomplished by the same, or at least highly similar, systems to those that help us to stop a physical action upon demand. By studying this model task, its functional properties, and the brain systems that underlie it, we hope to gain a better understanding of naturally occurring cases of motivated forgetting. In so doing, perhaps we may be able to better the circumstances of individuals for whom memory intrusions are debilitating. Nevertheless, voluntary suppression is unlikely to result in a "spotless mind," and certainly would not work as quickly as a "memory deletion" device. However, the slower, gradual human solution to forgetting unwanted memories may be a graceful compromise between the desire to expel what is unpleasant from our lives and the need to retain all experiences to grow as individuals.

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Encoding Deselection and Long-Term Memory

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Summary. Our information-rich environment increasingly requires us to process multiple sources of information simultaneously. These attentional demands can have long-term consequences for memory. A substantial empirical literature shows that long-term explicit memory is impaired following encoding tasks that require individuals to attend to two sources of information simultaneously. Such encoding demands do not, however, impair perceptual priming. Because perceptual priming is a robust measure, its resistance to division of attention is not entirely surprising. Yet attentional demands can have a negative influence even on perceptual priming when the encoding situation requires individuals to *ignore* information that was previously processed in order to focus on a different dimension. We discuss recent research on the fate of such *ignored* or *deselected information* in long-term memory. Because deselection is often necessary for accomplishing relevant goals in a variety of situations, a better understanding of its long-term effects can help explain fundamental cognitive processes that shape memory. In this chapter, we review evidence that shows that deselection effects on memory can be pervasive and that they can be resistant to different protective variables instantiated at encoding or retrieval. These findings show that the process of deselection is an important encoding mechanism underlying memory impairment.

Key words. Deselection, Stroop effect, explicit memory, perceptual priming, memory impairment

Introduction

It is common belief that simultaneous attention to two different sources of information harms cognitive performance. Yet increasing complexity in our environment is forcing us to simultaneously process multiple sources of information, distracting us from the primary information upon which we wish to focus. In many cases, planned activities place such demands on cognition. Consider, for example, writing emails while holding a telephone meeting, or viewing television shows that present multiple boxes of display—wildfire scenes beside an anchor person's face and voice while a ticker streams at the bottom of the display with text information. Faced with such situations, we must attend to the important or relevant information in our environment and simultaneously ignore (or deselect) information that is irrelevant to the goal at hand. The dynamic application of these complementary selection and deselection processes suggests that these are critical components of efficient cognitive functioning, and therefore central to any theory of human memory performance.

In our ongoing research, we have focused on these issues by addressing the consequences that deselecting a source of information has on the long-term representation of that deselected information in memory. Specifically, when two pieces of information compete for encoding and the dominant stimulus has to be deselected to choose the alternate stimulus, what mechanisms underlie such deselection and what are the long-term consequences of such deselection on memory?

In recent years, considerable effort has been directed toward understanding the consequences for long-term memory of such division of attention during encoding. In this line of work, attention is divided during the study (or encoding) phase of an experiment, usually by requiring participants to perform two concurrent tasks. For example, Anderson and Craik (1974) required participants to study a visually presented list of words. One group performed this task alone (Full attention condition); another group learned the items as they simultaneously monitored a series of tones (Divided attention condition). When asked to recall the words from the study list, participants in the divided attention group remembered fewer items than did those in the full attention group. This finding is representative: Dividing attention at encoding typically impairs performance on *explicit memory* tasks, tasks that require deliberate retrieval of the study event at the time of test (see Craik, 2001; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Naveh-Benjamin, Craik, Peretta, & Tonev, 2000, for recent reviews).

A longstanding debate exists among attention researchers regarding the precise nature of attention, and a variety of concepts have been subsumed under the single term "attention" (Pashler, 1994, 1998). In memory research, manipulations used to examine attentional effects typically fall into two categories: filtering tasks or monitoring tasks. Both of these tasks require participants to attend to (i.e., to select) target items, or a particular feature of target items, from among a set of distractors. The primary difference between filtering and monitoring tasks is that participants must attend to targets and ignore distractors in the former, whereas they must attend to both targets and distractors in the latter. Some of the filtering tasks commonly used in memory research are selective shadowing, focused attention, the Stroop task, and the flanker task. Commonly used monitoring tasks are tone monitoring, consonant monitoring, shadowing, target identification, and the attentional load manipulation. Although this particular classification is not the focus of present review, it is the case that the nature of attentional demands—in terms of attending to a target stimulus and ignoring a distracting stimulus versus simultaneously attending to both the target and distracting stimuli—is of consequence in assessing attentional effects on memory.

Simultaneous attention to a secondary task such as tone monitoring is commonly used in memory research, as exemplified by the Anderson and Craik (1974) study described earlier. In such cases, the secondary task is presumed to interfere with processing of the to-be-recalled words (Eysenck & Eysenck, 1979), particularly when that processing is elaborative or conceptual. If this is true, then performance should be particularly impaired on memory tasks that are sensitive to the meaning of the encoded words. Considerable effort has been directed in recent years to testing this possibility, with research on this issue strongly influenced by the tenets of the transfer appropriate processing framework originally proposed by Morris, Bransford, and Franks (1977) and more recently updated by Roediger and colleagues (Blaxton, 1989; Roediger, 1990; Roediger, Weldon, & Challis, 1989). This enhanced transfer appropriate processing approach specifies the processing requirements of numerous memory tasks in terms of meaning- or conceptually-based processes versus perceptual or data-driven processes and, as such, sets the stage nicely for assessing the mechanisms that underlie the interplay between attention and memory.

This line of work on processing distinctions has also revealed that memory is not a unitary phenomenon because encoding variables can exert opposite influences on different memory tasks as a function of the processing requirements of these tasks. Thus, any consideration of attentional effects on memory must take into account not only the specification of the encoding task that instantiates division of attention (filtering versus monitoring) but also the varieties of memory tasks, and of their processing requirements, on which the effects of distraction are measured.

Varieties of memory and division of attention

Reports of a dramatic dissociation in the performance of amnesic individuals have revealed a major distinction between two types of memory probes—explicit and implicit. The critical difference between implicit and explicit memory tasks is in the type of instructions given at the time of test. Explicit memory tasks, such as free recall, cued recall, and recognition, require deliberate retrieval of study material whereas implicit memory tasks make no reference to a prior study episode and instead typically entail providing the first response that comes to mind (Graf & Schacter, 1985). In implicit tasks, memory is assessed through *priming* scores by measuring the change in reaction time and/or accuracy between studied and nonstudied information. Performance of amnesic individuals is predictably impaired on tasks that require explicit or deliberate retrieval of study episodes but, quite remarkably, their performance is generally preserved on implicit memory or *priming tasks* (Graf, Squire, & Mandler, 1984; Shimamura & Squire, 1984; Warrington & Weiskrantz, 1970; see Moscovitch, Vriezen, & Goshen-Gottstein, 1993, for a review). Preservation of implicit memory performance in amnesia sparked widespread interest, and research on the nature of this form of memory, in amnesia as well as in individuals with intact memory, came to define a new field of inquiry.

Just as the dissociative effects of amnesia on different memory functions have advanced our understanding of the neural underpinnings of memory (Tulving & Schacter, 1990), dissociative effects of numerous experimental variables in research with healthy individuals also have revealed the processing requirements of various memory tasks (Blaxton, 1989; Roediger, 1990; Roediger, et al., 1989). For example, performance on recall, recognition, and similar explicit memory tasks improves following meaningful encoding of study material such as is brought about by levels of processing (Craik & Lockhart, 1972) and generation (Slamecka & Graf, 1978) manipulations. The conceptual basis of recall and recognition tasks suggests that division of attention at study should impair performance on these tasks because, as noted earlier, a secondary task is assumed to disrupt conceptual analysis of study material. Indeed, disruptive effects of divided attention on explicit memory performance appear to be ubiquitous, as demonstrated by adverse effects of digit or tone monitoring or dichotic listening at study (Eich, 1984; Isingrini, Vazou, & Leroy, 1995; Jacoby, Woloshyn, & Kelley, 1989; Mulligan, 1997; Mulligan & Hartman, 1996; Schmitter-Edgecombe, 1996a, 1996b). Interestingly, these methods of dividing attention at study have also been shown to affect explicit memory tests that use perceptual cues, tests such as fragment cued recall and stem cued recall (Mulligan, 1998; Mulligan & Hartman, 1996; Rajaram, Srinivas, & Travers, 2001; Schmitter-Edgecombe, 1996a). This is because deliberate access to a study episode entails reliance on conceptual processes even on tasks that provide perceptual test cues (Roediger, Weldon, Stadler, & Riegler, 1992), and therefore makes performance sensitive to attentional requirements.

The hypothesis that dividing attention disrupts conceptual processes is further supported by the evidence that divided attention at encoding disrupts even implicit memory performance if these tasks rely on conceptual processes (e.g., Mulligan & Hartman, 1996). To understand these effects, it is useful to consider the distinction between *conceptual* implicit memory tests (also called *conceptual priming* tests) and *perceptual* implicit memory tests (also called *perceptual priming* tests) first introduced within the enhanced transfer appropriate processing framework (Blaxton, 1989; Roediger, 1990; Roediger et al., 1989). A number of conceptual implicit tasks have been used to explore this distinction. For example, in the category production task, participants study a set of medium-frequency exemplars (e.g., donkey, pear) and are later given category names (e.g., animals, fruits) and asked to produce as many exemplars as they can within a given amount of time (e.g., 30 seconds). The increase in the probability of producing the target exemplars (donkey, pear) when they are studied relative to when they are not studied constitutes a measure of priming on these tasks (Srinivas & Roediger, 1990; see Roediger & McDermott, 1993, for a review of other tasks).

Performance on conceptual implicit memory tests benefits from meaningful (i.e., semantic) encoding at study, relative to encoding items for nonsemantic, or physical properties; better memory is observed if participants are required to make judgments on semantic characteristics of the presented item (e.g., Is this something you wear? SHIRT) compared to the physical aspects of the item (e.g., Is this word in uppercase letters? SHIRT). Conceptual priming is adversely affected when attention is divided at encoding (Gabrieli, Vaidya, Stone, Francis, Thompson-Schill, Fleischman, et al., 1999; Light, Prull, & Kennison, 2000; Mulligan, 1997, 1998; Mulligan & Hartman, 1996; Mulligan & Stone, 1999; Schmitter-Edgecombe, 1999, Experiment 2; but see Isingrini et al., 1995; Koriat & Feuerstein, 1976; Mulligan, 1997). This outcome is similar to the detrimental effects of division of attention on explicit memory tasks and consistent with the idea that division of attention disrupts conceptual analysis of target information. This outcome also suggests that if participants perform a nominally implicit task with explicit retrieval strategies (i.e., in violation of the instructions to perform the task with the first answer that comes to mind), the task would begin to tap into conceptual processes and would likely produce disruptive effects of divided attention. This logical inference about the connection between explicit retrieval and conceptual processes is important to bear in mind while evaluating attentional effects on various implicit tasks where possible contributions of explicit retrieval are not systematically controlled or measured.

In contrast to the consistent effects of division of attention on memory performance that relies on conceptual processes, effects of attentional changes on tasks that largely rely on perceptual processes have been inconsistent. These effects have been measured by performance on *perceptual implicit memory tests* that benefits from perceptual or feature-based encoding at study. In these tasks, participants are asked to complete impoverished test cues with the first response that comes to mind. For example, participants complete fragments such as _o_ke_ in the word fragment completion task, or stems such as don_____ in the word stem completion task, or they attempt to identify words presented at threshold durations (or under masked conditions) in the perceptual identification task. Better priming is observed on these tasks if the perceptual features remain constant between study and test (e.g., visual presentation in both cases) than if the similarity of the features is reduced (e.g., auditory presentation of items at study and visual presentation of items at test). Manipulating such perceptual information at study has little effect on conceptual implicit memory. The converse is also true: Manipulating semantic information has negligible effects on perceptual implicit memory.

In direct contrast to the attentional effects on recall and recognition, and on conceptual implicit memory tasks, division of attention has generally failed to impair performance on perceptual implicit memory tasks such as word fragment completion, word stem completion, perceptual identification, and lexical decision (Bentin, Kutas, & Hillyard, 1995; Jacoby et al., 1989; Mulligan & Hartman, 1996; Parkin, Reid, & Russo, 1990; Parkin & Russo, 1990; Schmitter-Edgecombe, 1996a, 1996b; but see Gabrieli et al., 1999). In these studies, division of attention during study was typically instantiated by requiring simultaneous tone or digit monitoring, or shadowing, or performance on a visual distractor task that did not compete with the processing of the target (Wolters & Prinsen, 1997).

But the picture is more complicated. Some studies have shown disruptive effects of dividing attention on perceptual priming tasks such as word fragment completion, perceptual clarification, lexical decision, and affect judgments (Hawley & Johnston, 1991; Seamon, Brody, & Kauff, 1983; Smith & Oscar-Berman, 1990; Weldon & Jackson-Barrett, 1993). A close inspection of encoding conditions in these studies suggests, however, that the disruptive effects are not attentional; rather, a failure to complete perceptual processing of targets appears to be the cause for impaired priming. Generally in these studies, participants were required to shadow or monitor secondary events in the same modality as the targets, and the manner in which these conditions were instantiated likely led to interference in the actual identification of targets. For instance, when the secondary task is combined with very short exposure duration (2 sec to 250 msec) for targets, word identification becomes nearly impossible (e.g., see Weldon & Jackson-Barrett, 1993). Because completion of perceptual-lexical analysis is known to be sufficient to support perceptual priming (see Weldon, 1991), the failure to properly encode targets reflects a perceptual rather than an attentional basis for disrupted priming in these studies.

Together, findings from different classes of memory tasks are interesting for several reasons. First, findings from explicit memory tasks and conceptual priming tasks support the assumption that secondary tasks that involve simultaneous processing of targets and distractors during encoding disrupt the conceptual analysis of targets while allowing for perceptual-lexical analysis to be completed. Second, perceptual priming studies support the contention that this type of priming is disrupted not by attentional factors but by failure to achieve proper (perceptual) encoding. Third, these findings are consistent with the claim that perceptual priming is a resilient form of long-term memory; we know from other lines of research that it is generally preserved even in profound cases of amnesia (Graf et al., 1984; Moscovitch et al., 1993; Shimamura & Squire, 1984; Warrington & Weiskrantz, 1970), that it does not usually depend on deep levels of processing during encoding (Graf & Mandler, 1984; Graf, Mandler, & Hayden, 1982; Jacoby & Dallas, 1981; Roediger et al., 1992; but see Brown & Mitchell, 1994; Challis & Brodbeck, 1992), that it survives long gaps between study and test (Jacoby & Dallas, 1981; Komatsu & Ohta, 1984; Roediger et al., 1992; Sloman, Hayman, Ohta, Law, & Tulving, 1988; Tulving, Schacter, & Stark, 1982), and, as summarized here, that it is also generally impervious to disruptive effects of attention.

A consideration of varieties of memory allows us to understand the ways in which attention can exert differential influence on long-term memory. But as we will describe shortly, the effects described thus far have typically been documented under encoding conditions that required processing of both target and distractor materials. In the following section, we will discuss the fate of ignored information—information that undergoes processing but must be ignored to complete the task at hand—in long-term memory because ignored information provides a measure of deselection effects. Consequences of deselection relate also to questions about the role of inhibitory control in suppressing unwanted memories and the resulting memory failures (see Anderson, this volume.)

Dividing attention between two sources versus ignoring one source

In general, research on the relation between attention and memory has focused on study conditions that require division of attention between a primary task (that includes the target) and a secondary task (that contains the distractor). These conditions do not address a different yet common situation where successful completion of a task demands that we ignore one source so that we can attend to the other. What are the consequences of *ignoring* a target on its long-term representation?

In fact, a recently burgeoning domain of study has focused on effects of ignoring targets on subsequent performance. It is now well-established that if a word or an object is ignored on trial *n-1* and becomes the attended target on trial *n*, response to this item is slower than to a baseline item that was not previously ignored (Tipper, 1985). This is the phenomenon of *negative priming* (for reviews, see Fox, 1995; May, Kane, & Hasher, 1995) and it demonstrates two important points—that the requirement to ignore a stimulus does not eliminate the processing of that stimulus, and that the processing of the stimulus and its subsequent deselection produces negative consequences on later performance. Negative priming seems to last as long as 6-8 sec and survives intervening events (Neill & Valdes, 1992; Tipper, Weaver, Cameron, Brehaut, & Bastedo, 1991). Even so, the time frame within which negative priming has been documented is relatively short and it remains an open question whether negative consequences of ignoring information can be long-lasting.

As we noted earlier, studies of perceptual priming have shown that for encoding to be of any interest, the basic perceptual-lexical analysis must be completed (e.g., Weldon & Jackson-Barrett, 1993). Thus, to study the long-term effects of ignoring a target, it is important to establish conditions where the target is processed first and then ignored; in other words, the target must be *deselected*, as has been the case in studies of negative priming. To the extent that a target is processed but subsequently deselected in order to complete the task at hand, would the initial processing be sufficient to support long-term memory? If so, would the effects of such deselection vary across different forms of memory? Or, does deselection negatively impact target representation and negate the positive influences of initial processing? In this section, we explore answers to these questions.

An early study by Hawley and Johnston (1991) included several conditions of interest that provide initial insight into some of these questions. In one of their experiments, the target and distractor items were presented during the study phase within a flanker task (e.g., 9 camel 2) for either 33 ms or 67 ms. Attention was divided by requiring participants to attend to specific aspects of the stimuli: The 100% group attended only to target words, the 50% group attended equally to reading words and to reporting the sum of two digits, and the 0% group attended only to the digit task. The 0% group is of particular interest here because it required participants to ignore a dominant response, i.e., reading the word. In fact, based on the finding that word identification dropped from 95% accuracy in the 100% group to 80% accuracy in the 50% group, these researchers inferred that word identification in the 0% group, where the words were not reported, was well above zero. Thus, to the extent that reading is a relatively automatic activity, it can be assumed that participants in this condition had to deselect the word that they automatically read in order to perform the task of attending to and summing the flanker digits.

Memory performance was measured with recognition (explicit task) and perceptual clarification (implicit task). Here, we focus on the implicit perceptual clarification task. This task is similar to the perceptual identification task and requires identification of words that are gradually clarified on the screen. Little priming was observed for the 0% group for the long (67 msec) exposure durations. These results suggest that perhaps the word was not processed in the first place. However, the short exposure duration condition (33 msec) revealed a very interesting pattern: Priming was *negative* in this condition. Negative priming in the perceptual clarification task suggests that participants were able to successfully deselect the words that they had processed, and that this cognitive act led to the inhibition of words. According to this analysis, an absence of priming in the 0%/long exposure duration condition suggests that initial processing of words coupled with only partially successful deselection (because of longer exposure) led to a summation of positive and negative priming effects, respectively. These results suggest an intriguing and somewhat disturbing conclusion: Deselection leads to long-term impairment in memory.

The absence of priming in one condition and the presence of negative priming in another condition in the Hawley and Johnston study is noteworthy for another reason: Priming deficits were observed in a perceptual priming task and, as we noted earlier, perceptual priming is arguably the most resilient form of memory. These findings imply that dividing attention between two sources versus attempting to ignore one source can in fact have different effects on long-term memory. Specifically, ignoring information, even though it was processed in the first place, can have long-term, negative consequences. The negative impact of such deselection can be found even on priming measures of memory that seem resistant to other adverse influences such as directed forgetting (see Anderson, this volume) and other factors noted earlier in our chapter. In the next section, we will describe the Stroop task model that allows a test of this issue.

Consequences of deselection: The Stroop task as a model

Reading is assumed to be an automatic or a default activity. A wealth of evidence that supports this assumption comes from a long history of research using the Stroop task (Stroop, 1935; and see MacLeod, 1991, for a review). In the Stroop task, words printed in different colors are presented either for word naming or for color naming. But words are identified at the lexical and semantic levels even in the color naming condition. For example, if the color name represented by the word matches the ink color (the congruent condition), the response time to name the color is faster than if the color name and ink color mismatch (the incongruent condition). Also, response times to name the ink color are faster if the string consists of Xs (a neutral stimulus) than if the string consists of a legal word. Slower reaction times document lexical and/or semantic access. In fact, even if slower response times are not observed, perceptual-lexical analysis has been shown nevertheless to take place in the Stroop (or the incongruent) condition (Besner, 2001). Thus, the Stroop task meets the conditions required to observe perceptual priming—perceptual-lexical access is afforded by this task. Yet, to complete the task at hand (i.e., color naming), the identity of the word has to be deselected because it is irrelevant to the task. As such, the Stroop task can serve as an excellent model to examine the consequences of deselection on long-term memory.

Indeed, negative consequences of Stroop encoding have been observed in studies that have used paradigms somewhat similar to those used in negative priming studies (see Neill, 1977). For instance, in a recent study reported by Catena, Fuentes, and Tudela (2002), participants were presented with a word in ink color on trial *n* (e.g., the word "yellow" presented in green ink). The word name (yellow) on this trial, that presumably had to be ignored to name the ink color, then became the ink color on the next trial, *n+1* (e.g., the word "blue" presented in yellow ink). Response times to name an ink color on trial *n* (e.g., yellow) were slower when the ink color represented a word that was ignored on trial *n-1* (e.g., yellow) compared to response times to name an ink color (e.g., red) that was unrelated to the ignored word on trial *n-1* (e.g., yellow).

The Catena et al. (2002) study demonstrates two critical points. First, on a given Stroop trial, the ignored word is indeed processed before its deselection (see also this study and Besner, 2001, for conditions where no Stroop interference was documented on trial *n*, yet *positive* priming was obtained on trial *n+1*, demonstrating once again that words are processed in the Stroop task even when response times fail to indicate this activity within that trial). Second, processing of words in a Stroop task does have consequences beyond a given trial because slowing occurs on a following, related trial.

The Stroop paradigm thus serves as a suitable model for creating conditions where both target processing and target deselection occur. With these requirements in place, this model situation can be effectively used to investigate whether deselection produces long-term consequences as well. We will now present a selective review of studies on this issue to illustrate the mechanisms that can specify the relation between deselection and long-term memory.

Stroop deselection and long-term memory

As we described earlier, studies in which divided attention is instantiated by requiring simultaneous processing of both targets and distractors have shown that whereas performance on tasks that tap into conceptual processes (explicit memory tasks and conceptual priming tasks) is impaired, performance on perceptual priming tasks remains largely intact. These findings suggest that performance on explicit memory tasks such as recall and recognition would be impaired even under those conditions where attentional variation is instantiated through item deselection during study. It is reasonable to assume that explicit memory performance would be sensitive to any form of attentional disruption. Furthermore, deselecting an item presumably truncates deeper levels of processing, or processing of meaning, and this curtailment should impair explicit memory performance. The key question of interest concerns whether there are consequences of deselection on perceptual priming because, as noted earlier, traditional methods of dividing attention at encoding do not impair this form of memory.

Numerous variations of the classic Stroop task exist in the literature but the studies reviewed here have typically used the following version of the paradigm. Words printed in different colors are presented for word naming (i.e., the full attention condition) or for color naming (i.e., the deselection condition). Under the deselection condition, identification of words does occur despite the fact that they are irrelevant to the task; this is shown by significantly slower color naming of words compared to color naming of neutral stimuli such as a row of Xs or nonsense letter strings (e.g., Besner, 2001; Dalrymple-Alford, 1972).

Although only a small set of studies have examined the effects of Stroop encoding on explicit memory tasks, the findings are entirely consistent across them: Stroop encoding produces substantial impairment in explicit memory performance. Szymanski and MacLeod (1996) reported poorer recognition memory for words studied under Stroop encoding conditions relative to words studied with full attention. In our work, we have reported substantial impairment on a task of word stem cued recall following Stroop encoding compared to reading the word (Rajaram et al., 2001, Experiment 2). More recently, we have also replicated Szymanski and MacLeod's (1996) findings on a recognition memory task (Travers & Rajaram, 2004).

The effects of Stroop encoding on perceptual priming have been investigated across a wide variety of tasks, and with a few exceptions, the findings are remarkably consistent here as well. These studies reveal a very interesting pattern: Stroop encoding *impairs* perceptual priming although it does not eliminate it. This reduced priming has been reported with the word fragment completion task (Rajaram et al., 2001, Experiment 1), the word stem completion task (Rajaram et al., 2001, Experiments 2 and 3; Travers & Rajaram, 2004), and the perceptual identification task (Mulligan & Hornstein, 2000; Stone, Ladd, Vaidya, & Gabrieli, 1998).

In a limited number of cases, Stroop encoding failed to produce the pattern of reduced (but still significant) priming. In one case, Stroop encoding did not reduce priming at all on a lexical decision task where participants had to decide as quickly as possible whether a letter string constituted a legal English word (Szymanski & MacLeod, 1996); in another case, Stroop encoding did not produce significant priming on a perceptual identification task (Stone et al., 1998, Experiment 3). The lack of reduction in priming on the lexical decision task might be attributed to the possibility that this task often produces results that are not in line with the commonly used perceptual priming tasks such as word fragment completion, word stem completion, and perceptual identification (see Rajaram & Roediger, 1993, for evidence). Nevertheless, equivalent priming for Stroop encoding and full attention encoding in the lexical decision task confirms an important point that was amply demonstrated in studies reviewed in the previous section: Stroop encoding entails processing of words. Thus, the Szymanski and MacLeod study constitutes one documented case where perceptual priming remained impervious to deselection effects. The lack of significant priming on the perceptual identification task in the Stone et al. study is more puzzling because reduced yet significant priming was observed in another experiment of that series and has also been reported in several experiments by others (Mulligan & Hornstein, 2000).

Regardless, the bulk of studies have reported reduced but significant priming as a result of Stroop encoding. In our study (Rajaram et al., 2001), we measured the response times during encoding to name the color in the Stroop condition and in a neutral condition (strings of Xs) and found significant Stroop interference (see the top half of Figure 1). At test, we replicated the reduction in priming across word fragment and word stem completion tasks by holding the stimuli and a number of other methodological details constant across tasks.

Parallel patterns of reduced priming for Stroop encoding across these two tasks rule out the potential concern that findings from the stem completion task may be specific to the processing demands of this particular task and, as noted earlier, reduced priming has also been observed with the perceptual identification task (Mulligan & Hornstein, 2000; Stone et al., 1998, Experiment 2). In fact, reduced priming in the perceptual identification task occurs even when participants are asked to read the word first and then to name the color, or are asked to name the color first and then to read the word, demonstrating that reduced priming cannot be attributed to a failure to encode the word (Mulligan & Hornstein, 2000). These three tasks—word fragment completion, word stem completion, and perceptual identification—are considered to be representative tasks of perceptual priming (see Roediger & McDermott, 1993, for a review). Therefore, consistent patterns of reduced priming across these tasks have considerable theoretical significance.

Before the theoretical significance of these findings can be evaluated, there is one potential concern about these data that warrants discussion. A reduction in priming in any implicit task inevitably raises questions about a possible involvement of explicit retrieval. Because explicit memory is highly sensitive to any attentional variation, a reduction in priming could result if test conditions did not prevent the use of intentional retrieval. Therefore, in one experiment, we directly contrasted effects of Stroop encoding on implicit stem completion and explicit stem cued recall tasks (Rajaram et al., 2001, Experiment 2). A direct contrast of explicit and implicit tasks, where the entire method and procedure are held constant except for the change in retrieval instructions, is considered to provide a powerful assessment of the contributions of intentional retrieval and a pure assessment of implicit memory performance (Schacter, Bowers, & Booker, 1989).

Under these test conditions, we found that full attention to words (i.e., reading) enhanced explicit stem cued recall performance relative to implicit stem completion performance. In contrast, Stroop encoding impaired explicit stem cued recall performance even more than the reduction that we observed in the implicit stem completion task. This cross-over interaction

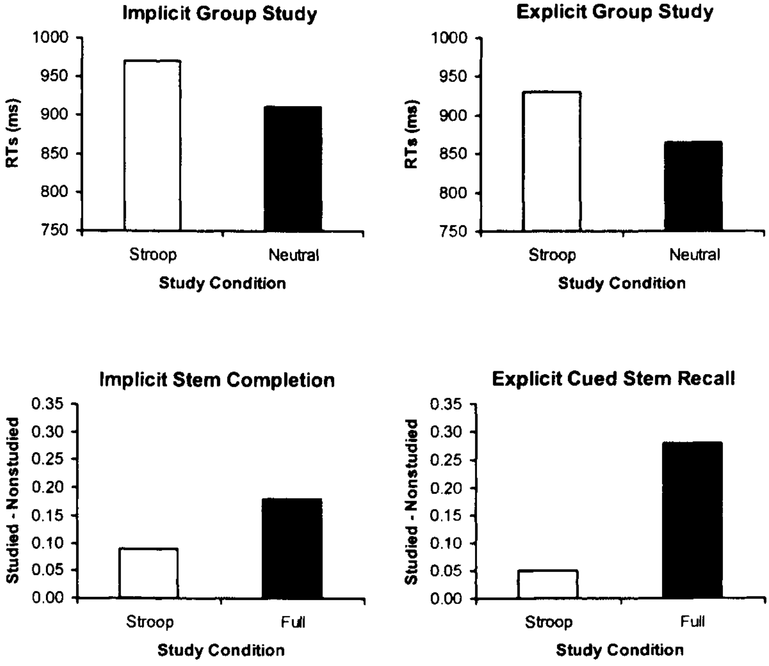

Fig. 1. Study and test performance data taken from Rajaram, Srinivas, & Travers, 2001 (Experiment 2).

is displayed in the bottom half of Figure 1. The benefit from full attention and the larger reduction from Stroop encoding on stem cued recall demonstrate that performance on the implicit stem completion task was not contaminated by explicit retrieval strategies and that it reflected the effects of deselection on perceptual priming.

In fact, we took an additional step in Experiment 3 to rule out the possible role of explicit retrieval in perceptual priming by using a post-test awareness questionnaire (Bowers & Schacter, 1990). After completing the implicit word stem completion task, participants filled out a questionnaire that queried whether they had realized the connection between the study and test phases. Based on these responses, performance of 17 of 89 participants was eliminated from analysis without disturbing the counterbalancing. Once again, we observed reduced (though significant) priming in the Stroop encoding condition relative to the full attention condition.

Together, these studies show that both explicit memory performance and perceptual priming are adversely affected by the requirement to deselect information during encoding. This impairment is greater in explicit memory performance compared to perceptual priming. That impairment occurs at all in perceptual priming is an important discovery because this form of memory is considered to be impervious to a number of independent variables that impair explicit memory performance. As noted earlier, these variables include effects of amnesia, long retention intervals, and the impact of simultaneously attending to two sources of information.

Mechanisms underlying deselection effects in perceptual priming

The preceding review indicates that reduced (though significant) priming from Stroop encoding cannot be attributed to a failure to encode the word or to the use of explicit retrieval strategies. Instead, this finding demonstrates disruptive effects of active deselection of stimuli on long-term perceptual priming. We proposed the following account to explain this phenomenon (Rajaram & Srinivas, 1998; Rajaram et al., 2001). The requirement to deselect the word as the target response requires inhibition of word identity because word identity is irrelevant to the task at hand and interferes with color naming (see also Stone et al., 1998, for this assumption). The possibility of long-lasting, inhibitory effects from deselection has been considered in the literature on negative priming as well (see Tipper, et al., 1991; and Tipper, 2001, for a review). Thus, the need to inhibit word identity should lead to long-lasting negative priming. However, processing of word identity that also occurs during Stroop encoding should produce positive priming. We have proposed that these negative and positive effects sum together and result in reduced levels of priming (Rajaram et al., 2001).

According to this account, both processing of word identity and its active deselection are necessary for reduction in priming to occur. Several findings support this proposal. It has been shown that if participants are asked to ignore a single word then priming is not reduced for that word (MacDonald & MacLeod, 1998, Experiments 1 and 2). But if two words are presented simultaneously and one must be ignored to attend to the other designated as the appropriate target, no priming is observed for the ignored word (Crabb & Dark, 1999; MacDonald & MacLeod, 1998, Experiment 3). In the former condition, the word is processed but not deselected. But in the latter condition, the ignored word is physically separated from an equally dominant target (i.e., another word) and, therefore, suffers more than might be the case in the Stroop task, where the competing dimensions are integrated and simultaneously processed. As a result, impairment is greater when two equally dominant dimensions (i.e., words) compete with each other but one can be easily ignored due to physical separation than when a dominant dimension (i.e., word) competes with a less dominant but integrated dimension (i.e., color name) and is difficult to ignore. This is similar to the explanation offered by MacDonald and MacLeod (1998) for their findings.

It should be noted that the distinction between integrated and separable dimensions of stimuli is made on the basis of processing requirements and not on the basis of physical separation alone. As just noted, if two words are presented simultaneously but participants are required to attend only to one of them, the ignored word failed to produce priming (MacDonald & MacLeod, 1998, Experiment 3). Similarly, if two dimensions such as color and word are physically separated and participants are required to attend to only one dimension (color), priming fails to be significant for words (Mulligan & Hornstein, 2000, Experiment 4). However, if the two dimensions are separated but participants are asked to simultaneously attend to both dimensions, competition for the selection of the appropriate dimension ensues. Under these conditions, words show significant priming although that priming is reduced in comparison to a full attention condition (Mulligan & Hornstein, 2000, Experiment 4).

A potential problem for our account of deselection comes from a negative priming study where repeating a distractor (a picture) from trial *n* again on trial *n+1* dissipated negative priming for that picture on trial *n+2* (Tipper, et al., 1991, Experiment 6). If negative priming dissipated with repetition in these studies, then no reduction should be observed in long-term priming either. However, as noted earlier, even when participants first named the color and then read the word within one trial, perceptual priming was reduced on a later priming task (Mulligan & Hornstein, 2000). Furthermore, other evidence also suggests that although negative priming dissipates in the short term for novel shapes, it returns at longer intervals (DeSchepper & Treisman, 1996). In other words, short-term dissipation in negative priming is not predictive of long-term reduction in priming.

It should also be noted that there are a number of procedural differences across these studies, including the nature of stimuli and the number of repetitions within or across trials, that make it difficult to draw straightforward conclusions. Clearly, this issue needs closer examination before a possible relation between short-term and long-term negative priming can be ascertained. To the extent that the present evidence on this issue is limited as well as contradictory, and that it rests on cross-study comparisons, the proposed deselection account (Rajaram et al., 2001) continues to provide a fruitful framework for understanding inhibitory effects of deselection on long-term priming.

An alternate account of reduced priming for Stroop stimuli appeals to the idea of encoding disruption (Mulligan & Hornstein, 2000). According to this account, when two stimuli compete and a response is required to the distractor (in this case, color name), the memory encoding of the target (in this case, word) is disrupted. This account is based on the argument that first naming a color and then reading a word within one trial should remove inhibition for the word and restore priming to normal levels but, as noted earlier, priming is not restored under these conditions. However, it also follows that reading the word subsequent to color naming should repair disrupted encoding and thereby restore priming. As such, reduced priming in the color name-then-read condition is problematic for the encoding disruption account.

Regardless of variation in the details of different accounts that can fully capture the mechanisms underlying reduced priming, it is now abundantly clear that deselecting a processed target results in long-term memory impairment. This impairment cannot be attributed to lack of processing of the target itself or to contamination from the use of explicit retrieval strategy. Thus, even the most resilient form of memory, long-term perceptual priming, depends on attentional processes.

Protecting the target from deselection effects

Disruptive effects of deselection on long-term memory are reliable. Yet deselection seems unavoidable in light of competition among the multiple sources of information that we process continually. Is it possible to counteract the disruptive effects of deselection by systematically manipulating the encoding and retrieval factors that operate on memory? We have recently begun a series of studies to answer this question (Travers & Rajaram, 2004).

In one study, we arranged the encoding conditions to protect the item from the disruptive effects of deselection. To achieve this, we introduced spaced repetition during encoding. Spaced repetition of stimuli is known to enhance explicit memory performance. Specifically, spacing between repetitions of stimuli is assumed to enhance encoding and, in particular, to enhance the encoding of the second presentation (Greene, 1990, 1992). As such, this variable could serve nicely to protect the processing of word identity in the Stroop condition. Under this type of enhanced encoding of stimuli in the Stroop condition, would long-term priming be restored?

To answer this question, we constructed two study phases. In Phase 1, all words were presented for pleasantness rating. In Phase 2, one third of the items from Phase 1 were repeated with instructions to simply read them (Read-2 condition), one third of the items from Phase 1 were repeated with instructions to name their colors (Stroop-2 condition), and one third of the items from Phase 1 were not presented again (Read-1 condition). In addition, in Phase 2, strings of Xs were also presented to serve as neutral stimuli for color naming so that the interference in the Stroop-2 condition could be measured. Following a 5-minute retention interval, half of participants in each of the three conditions were presented with an implicit word stem completion task and half were presented with an explicit stem cued recall test, using exactly the same cues in the two tests.

Findings from Phase 2 showed a Stroop interference effect: Participants took longer to name the colors of the words than of the neutral stimuli. This was true for both test groups. For the test data, overall performance on studied items was significantly higher in the explicit task than the implicit task, confirming that participants did not use explicit retrieval strategies in the implicit tasks. The key question concerned the effects of repetition on stem cued recall and stem completion performance. Repetition did enhance overall performance such that there was more priming in both of the repeated conditions (Read-2 and Stroop-2) than in the Read-1 condition on both the explicit and implicit tasks. Interestingly, repetition failed to restore priming in the Stroop-2 condition relative to the Read-2 condition; even though spacing is assumed to enhance the encoding of the second stimuli, this boost could not fully counteract the disruptive effects of word deselection. This was true on both of the tests. A continued reduction in priming despite the inclusion of protective encoding conditions demonstrates the power of deselection on long-term memory.

In another study, we focused on retrieval factors. To do so, we created retrieval conditions that are more optimal for performance than those available in typical perceptual priming tasks. For instance, tasks such as word stem completion and word fragment completion present only partial information about the target item. Similarly, although the perceptual identification task presents the entire word, it is presented at threshold durations, thereby impoverishing the test cues. Interestingly, in one instance of an implicit task where the item was presented in full view—the lexical decision task—no decrement in priming was observed (Szymanski & MacLeod, 1996). Therefore, we selected the recognition memory task to fully reinstate the study item with unlimited exposure time.

We did not expect the overall recognition performance to be equivalent between the Stroop and full attention conditions because prior evidence has already shown that recognition memory is impaired for Stroop-encoded items (Szymanski & MacLeod, 1996). Instead, we conducted the recognition memory task with the Remember-Know procedure (Tulving, 1985) to examine the effects of Stroop encoding on different components of recognition. A wealth of research has shown that Remember and Know responses capture qualitative differences in explicit memory performance (see Gardiner, 2002; Rajaram, 1999; Rajaram & Roediger, 1997; for reviews).

Under the Remember-Know procedure, participants are asked to give Remember judgments when they recognize an item because something specific about it from the encoding phase can be brought to mind at the time of test, such as the way the item looked or what the participant was thinking when they encountered the item during encoding. In other words, the memory for this item is accompanied by a sense of immediacy, or the participant can mentally travel back in time to the place where the item was encountered. In contrast, participants are asked to give Know judgments to recognized items if they are certain that the item was presented for encoding and it looks familiar but they cannot retrieve any specific information about its occurrence on the study list.

The underlying bases of Remember and Know judgments have been conceptualized in different although often complementary ways in different theories. These theoretical distinctions are not central to the purpose for which we selected this procedure in our study. Therefore, we direct the reader to sources where these theories are discussed (Gardiner, 2002; Jacoby, Yonelinas, & Jennings, 1997; Rajaram & Roediger, 1997; Tulving, 1985, 1989). For present purposes, it is useful to note that more recent research shows that Remember responses are particularly sensitive to distinctive aspects of study information (Mantyla, 1997; Rajaram, 1996, 1998) and Know responses are particularly sensitive to fluency factors (Rajaram, 1993; Rajaram & Geraci, 2000). Furthermore, although perceptual priming and Know judgments are not considered isomorphic, research has also shown that Know responses often respond to independent variables in ways similar to the way that perceptual priming responds (e.g., see Gardiner, 1988). In fact, like perceptual priming, Know responses are not sensitive to effects of divided attention when instantiated through the standard secondary tasks, such as tone monitoring (Gardiner & Parkin, 1990).

Taking into consideration these properties of Know judgments, it appears that these judgments create test conditions where the study item is fully reinstated but they do not demand recollective details for successful performance. Instead, Know judgments are based on familiarity or fluency.

As such, Know judgments create optimal retrieval conditions that are usually not afforded either by most explicit memory tasks or by most perceptual priming tasks. If deselection effects can be overcome with optimal retrieval conditions, then impaired recognition for Stroop stimuli should be limited to Remember judgments that do demand distinctive, recollective details, and little disruption should be observed on Know judgments. However, our findings showed that, relative to the Full attention condition, performance was impaired on both Remember and Know judgments in the Stroop encoding condition.

Together, the set of experiments in Travers and Rajaram (2004) demonstrates that deselection effects on memory are powerful and pervasive, and that they are resistant to protective factors whether introduced at encoding or at retrieval. These experiments underscore the need to better understand different ways in which attention interacts with long-term memory.

Concluding remarks

Amnesia is perhaps the most salient demonstration of memory failure. In healthy individuals, false memories also serve as remarkable examples of memory frailty. However, a number of other, less obvious, mechanisms also contribute to memory impairment in significant ways. Because these factors operate in pervasive ways, a comprehensive account of these factors is essential for understanding human memory function. Some of these mechanisms, such as output interference (Anderson, Bjork, & Bjork, 1994; Neely, Schmidt, & Roediger, 1983; Roediger, 1974; Tulving & Arbuckle, 1963), part-list cuing (Rundus, 1973; Slamecka, 1968; Sloman, Bower, & Rohrer, 1991), and retrieval-induced forgetting (Anderson, this volume; Anderson et al., 1994; Anderson & Spellman, 1995; Butler, Williams, Zacks, & Maki, 2001; Perfect, Moulin, Conway, & Perry, 2002) operate during retrieval. The mechanism of deselection described in this chapter operates during encoding. Because deselection is required in a wide variety of situations to accomplish relevant goals, a better understanding of its long-term effects has become increasingly important. Evidence reviewed in this chapter shows that deselection effects on memory are powerful in that they impair even resilient forms of memory, they are resistant to different forms of protective factors, and these effects certainly influence long-term memory.

Author Notes

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List Method Directed Forgetting: Return of the Selective Rehearsal Account

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Summary. Explanations of directed forgetting—the poorer memory for information that we are instructed to forget (F items) than for information that we are instructed to remember (R items)—have featured two classes of accounts: rehearsal and retrieval. Under the rehearsal account, the argument has consistently been that R items are selectively rehearsed more than F items. Retrieval accounts have been more varied, but the concept of retrieval inhibition has become prevalent, the idea being that F items are suppressed following a forget instruction. For the last 10-15 years, these two explanations have been attached to the two most common procedures in directed forgetting studies: selective rehearsal to the item method, where individual items are randomly assigned instructions, and retrieval inhibition to the list method, where half the list is designated as to-be-forgotten. We report serial position and test warning effects that demonstrate clear selective rehearsal effects in the list procedure. We argue that a separate retrieval inhibition account of the list method is not parsimonious; rather, a selective rehearsal explanation can readily accommodate the principal results obtained under both procedures.

Key words. Directed forgetting, rehearsal, selective rehearsal, inhibition.

Introduction

"Every time I learn something new, it pushes some old stuff out of my brain. Remember when I took that home winemaking course, and I forgot how to drive?"—Homer Simpson, *The Simpsons* (Daniels & Baeza, 1994)

The importance of forgetting is widely undervalued; indeed, people often profess the desire to banish forgetting entirely. This distaste for forgetting can be seen from the earliest views on memory. The ancient Greeks had two goddesses to represent the importance of remembering and forgetting, both daughters of Uranus (heaven) and Gaea (earth). Titaness Mnemosyne was the goddess of memory and the muse of remembering; her sister Lesmosyne presided over forgetting. Yet Mnemosyne was revered as by far the more important of the two. In part, this "higher profile" derived from her children with Zeus: Their nine daughters, the Muses, played a central role in memory mythology because cultural memories were preserved and shared through literature, art, song, poetry, dance, and theatre. Thus, Mnemosyne presided over memory and her children provided the means of preserving those memories.

In Greek mythology, the importance of remembering is emphasized, with forgetting viewed as the negative result of an inability to remember. Even Lesmosyne herself appeared to discount the importance of forgetting, stating, "that Memory should bear 'forgetfulness' is an oxymoron and almost a pun" (Caldwell, 1987). Unfortunately, little is known about Mnemosyne, who is featured in few myths. Ironically, however, even less is known about Lesmosyne, who is all but forgotten. Undeniably, the tradition of discounting the importance of forgetting in light of the importance of remembering is one of long standing.

In modern times, as illustrated in the opening quote, Homer Simpson's never-ending battle with his feeble memory is highlighted in many episodes of the popular cartoon. Like the Ancient Greeks and most of his non-fictional contemporaries, Homer views his memory loss as a problem, neglecting the benefits associated with "failures to remember." Indeed, forgetting is almost universally perceived as negative, often described using such loaded terms as memory "failure," "loss," or "impairment," all terms that emphasize the apparently detrimental aspects of forgetting. Who would not want a perfect memory?

Certainly the benefits of remembering are more apparent than are those of forgetting. Our ability to remember is clearly important not only for normal day-to-day functioning, but also for the development and maintenance of a sense of self (see, for example, Kihlstrom, Beer, & Klein, 2003). We rely heavily on this ability, admiring those, like top *Jeopardy* contestants, with exceptional memories. Yet the importance of forgetting should not be underestimated. It is axiomatic that to remember important information without confusion we need to forget extraneous and no longer relevant information. Old information can interfere with memory for new information, like remembering where you parked each day when you leave work: To find your car, you must forget where you parked on previous trips and remember today's location. Moreover, we often want to or need to forget, as in the case of a particularly embarrassing, sad, or traumatic incident. A world without forgetting would not be nearly as idyllic as many believe. Perhaps the most compelling example is the true story of the mnemonist Shereshevsky (Luria, 1968), a man with an extraordinary memory who became overwhelmed and imprisoned by the sheer volume of detail that he remembered. It seems that a memory not decluttered by forgetting interferes with normal functioning. In the words of William James (1890), "in the practical use of our intellect, forgetting is as important as recollecting."

We certainly agree with James that successful remembering is related to our ability to forget information that should be forgotten. Forgetting is especially important in memory updating (see Bjork, 1978; 1989)—replacing old information with new information to eliminate problems resulting from interference between old and new. Information can be forgotten unintentionally through the normal processes of forgetting or it can be forgotten intentionally by actively trying to suppress information or by following directions or instructions to forget. This chapter will focus on the second of these possibilities—intentional forgetting as a function of directions or instructions to forget.

Intentional forgetting is important at the individual level; for instance, we might want to suppress a personal memory of a loss or trauma that is particularly painful (Freud, 1900, 1938). It is also important at a more social level; for instance, when a judge orders that inappropriately presented information must be ignored or forgotten by a jury. In fact, in these and many other cases, it is not easy to forget despite the desire to do so (e.g., Wegner, 1994; see also Golding & Long, 1998). Nevertheless, under some conditions, people can intentionally forget, and this effect can be quite robust.

The paradigm that most successfully captures intentional forgetting in the laboratory is the *directed forgetting paradigm*. Using a simple word list learning procedure, during which the participants are instructed to forget a subset of the newly acquired information, numerous studies over the past 35 years have shown that to-be-forgotten information is quite easily forgotten, often to the benefit of the to-be-remembered information (for reviews, see Golding & Long, 1998; Johnson, 1994; MacLeod, 1998). Contrary to the prevalent belief that telling someone to forget something will actually make it even more memorable, the research shows that information can be successfully forgotten upon instruction.

Directed Forgetting Methods and Terminology

There are two primary variations of the directed forgetting paradigm which differ in how the memory instructions are presented. Under both methods, the participant is instructed to forget some items, the to-be-forgotten (F) items, and to remember other items, the to-be-remembered (R) items. In the *item method*, there are multiple apparently random R and F cues, one instruction immediately following each individual list item (e.g., MacLeod, 1975). In contrast, in the *list method*, two cues are typically presented, one at the middle (usually the forget instruction) and one at the end of the list (e.g., Elmes, Adams, & Roediger, 1970), although other list method variations have been introduced (e.g., MacLeod, 1975).

Following the study phase, in which the participant is told to remember or to forget subsets of the items, there is a free recall task in which the participant is asked to retrieve both the R items and the F items, despite having been told at the outset of the study that they would not be tested on the F items. Both list method and item method directing forgetting paradigms reveal that R words are advantaged compared to F words, although the difference apparent under the item method is attenuated under the list method (see, e.g., MacLeod, 1999). The usually observed recall advantage for the R items over the F items has been dubbed the *directed forgetting effect*.

The directed forgetting effect can be measured in two different ways. The first measure emphasizes the R items, employing a cost-benefit analysis of the differences in recall accuracy among three conditions: (a) the standard directed forgetting condition with an equal mix of R and F items (the entire list), (b) a condition with the R items only—half of the list, and (c) a condition with the entire list composed of R items (see MacLeod, 1998, for further details). The *directed forgetting benefit* is the recall advantage for the R items when coupled with an equal number of F items (condition a) as opposed to an equal number of R items (condition c). How much does the replacement of some R items with F items help the recall of the remaining R items? In contrast, the *directed forgetting cost* is the recall disadvantage for the R items when coupled with an equal number of F items (condition a) compared to a condition in which the list is half as long and made up of R items only (condition b). How much does adding F items to the list hurt recall of the R items?

The second measure emphasizes the F items, in contrast to the R items. This measure is simply the difference in recall between the R items and the F items (the *remember-forget difference*). Under the list method, this measure can be taken in two ways: as the difference between sub-list 1 (F) and sub-list 2 (R) in a within-subjects design, or as the difference between sub-list 1 (F) in a F-R instruction ordering condition and sub-list 1 (R) in a R-R instruction ordering condition. We see the latter measure as a more accurate calculation of the remember-forget difference in list method directed forgetting because the control condition removes the list order confound inherent in the within-subjects design (see Anderson, this volume, for further discussion on this point). Interestingly, however, the former measure is quite common in the literature. We should also highlight that the remember-forget difference measure is more commonly reported in the literature than is the cost-benefit technique as the preferred index of directed forgetting.

Although not yet directly compared empirically—work is in progress in our laboratory—there is also variability in the presentation of list method directed forgetting instructions. In the *simple cue paradigm* (e.g., Horton & Petruk, 1980), a single cue signifying "forget" (e.g., a color change, a symbol, or FFFFFF) is presented after the F sub-list without any explanation as to why these words should be forgotten. In the classic *deception paradigm* (e.g., Sahakyan & Kelley, 2002), following presentation of the F sub-list, the participants are told that the previous list was for practice and therefore that they can forget the items just presented (in a variation, the F sub-list is represented as a mistake, with participants told that the list can be forgotten). The subsequent R list is then presented as the real to-be-tested list. This discounting of the first sub-list and emphasis on the second sub-list effectively constitutes the directed forgetting instruction. Finally, in the *multiple cue training paradigm* (e.g., MacLeod, 1999) version of the task, participants are told from the outset that they will be presented with lists of words to learn, but that following each list they will be given an instruction to remember or to forget the previous list. Training trials prior to the experiment teach the participants the nature of the F-R cues, helping to solidify the belief that only the R items will have to be recalled at test. During the actual experiment, the first sub-list is given a F cue and the second sub-list a R cue, and the entire list is followed by an instruction to recall both the R and F items, countermanding previous instructions. We are currently exploring the differential effect of instructional type (simple cue, deception, multiple cue training) on the directed forgetting effect and more broadly on the underlying theoretical mechanisms.

In this chapter, we will center our attention on list method directed forgetting. Johnson (1994) argued that this is the only "true" directed forgetting, in that the instruction is given not during but after learning, thereby truly constituting a cue to forget rather than a cue not to learn. Although we believe that both methods have their value in helping us to understand forgetting, and we will ultimately argue that essentially the same mechanism is invoked by both methods, we will focus this chapter on the list method because it is primarily here that the rehearsal/inhibition battle has been waged. To understand the importance of this debate, we now introduce the various explanations that have been offered for the directed forgetting effect.

Theoretical Accounts of Directed Forgetting

Until quite recently (Basden, Basden, & Gargano, 1993; Bjork, 1989), theoretical accounts of the directed forgetting effect did not distinguish between the list and item method directed forgetting paradigms. Instead, unified theories were presented to account for all directed forgetting findings, regardless of procedural differences. The first true directed forgetting experiment was conducted by Muther in 1965, although Bjork, LaBerge, and Legrand (1968) really ignited directed forgetting research and led us into the "The Golden Age" of directed forgetting research through the 1960s and 1970s (MacLeod, 1998). Speculation about the theoretical underpinnings began with these first experiments. Almost immediately, the *deletion/erasure hypothesis* was rejected (Bjork et al., 1968; Muther, 1965) because F items clearly were not entirely expunged from memory, as demonstrated by their intrusion in recall (Muther, 1965).

One of the other earliest theoretical accounts of directed forgetting was the *repression account*, influenced by the parallels with clinical ideas of repression. This view posited inhibition of F items to reduce the extent to which they interfered with R items (Weiner, 1968; Weiner & Reed, 1969). But this view also quickly was set aside in the early years, displaced by two other theoretical positions, one emphasizing encoding and the other retrieval. Under the *selective rehearsal account*, rehearsal favored the R items, leading to better encoding of the R items than of the F items (see Bjork, 1972, for a review). Under the *selective search account*, when it was time for retrieval, participants largely restricted their search to the set of R items, segregated during study from the F items (see Epstein, 1972, for a review).

Selective search relied on the idea that participants separated items in memory by actively tagging them as either R or F during study, creating two instructionally distinguished sets. At test, the F items were ignored to the extent possible and the R items were selected for retrieval. Early segregation and selective search ideas had an inhibitory aspect: The items tagged as F were somehow suppressed or inhibited at retrieval and only the R items were actively retrieved (e.g., Elmes et al., 1970; Epstein, 1969). Although the inhibitory element was not emphasized, this view clearly represents one of the precursors to the current retrieval inhibition account. Epstein's early work did not unambiguously support the segregation and selective search account over the selective rehearsal account (e.g., Epstein, Massaro, & Wilder, 1972; Epstein & Wilder, 1972; Shebilske, Wilder, & Epstein, 1971), yet in his review Epstein (1972) emphasized the importance of selective search and rejected findings that differential rehearsal might have an effect on directed forgetting as uninteresting, similar to the position which Johnson (1994) later adopted in her review.

Selective rehearsal was not, however, without advocates. Although initially rejecting it (Bjork et al., 1968), Bjork soon came to prefer the selective rehearsal explanation. The selective rehearsal explanation simply proposes that items cued as R are rehearsed more than items cued as F, which may be rehearsed only minimally. At test, the items that received the most rehearsal during encoding are the most easily recalled, thus R items are retrieved more readily than are F items. Bjork (1970), like Elmes et al. (1970) and Epstein (1969), argued that participants use the F cue to segregate R and F items, but he further proposed that once the items were separated the participants selectively rehearsed only the R items, which served to strengthen the set differentiation. It is interesting to note that the specifics of the selective rehearsal account varied from an emphasis on the effect of selective rehearsal at encoding (Bjork, 1970) to retrieval (Woodward & Bjork, 1971) and back to encoding (Bjork & Woodward, 1973). Although the timing of the influence of selective rehearsal was not clear-cut, Bjork's explanation of the directed forgetting effect clearly emphasized two elements: the selective rehearsal of R items, and the segregation of R and F items in memory (Bjork, 1972). For most of the 1970s, the selective search and selective rehearsal theories of directed forgetting dominated the field.

By the late 1970s, however, an old idea was garnering new support. Retrieval inhibition, the account championed by Weiner in the 1960s (e.g., Weiner, 1968; Weiner & Reed, 1969) had fallen into disfavor after the very early years of directed forgetting. Weiner and colleagues had proposed that F and R items were not differentially learned, but that F items were harder to retrieve because they were repressed or inhibited. In the late 1970s, the inhibition view re-emerged, in large part as findings apparently inconsistent with a rehearsal explanation began to appear. In contrast to their earlier views, Bjork, Geiselman, and colleagues reported a series of studies, the findings of which could not easily be explained by selective rehearsal or selective retrieval accounts (e.g., Geiselman & Bagheri, 1985; Geiselman, Bjork, & Fishman, 1983). For instance, they observed directed forgetting under conditions in which selective rehearsal would appear to have been irrelevant or impossible.

Instead, Bjork, Geiselman, and colleagues (e.g., Geiselman & Bagheri, 1985; Geiselman, Bjork, & Fishman, 1983; Geiselman & Panting, 1985) argued that F items were inhibited during retrieval but could, under certain conditions (most notably re-presentation), be released from inhibition. The release from inhibition findings were seen as evidence against selective rehearsal: Clearly the items had been encoded if they could later be recalled, thus it was assumed that at the time of free recall the items were in memory but inaccessible. This revived inhibition account of directed forgetting has led to a continuing debate between encoding-based rehearsal views and retrieval-based inhibitory views of directed forgetting, as we have discussed elsewhere (MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003).

Early accounts of the directed forgetting effect were applied to differences obtained under both item method and list method directed forgetting. However, in 1989, Bjork suggested that different mechanisms could underlie the two methods. Bjork (1989) and Basden et al. (1993) proposed a simple dichotomy—that selective rehearsal underlies item method directed forgetting whereas retrieval inhibition underlies list method directed forgetting. Under item method instructions, the participant may delay rehearsal until an R or F cue is presented. Upon presentation of an R cue, the participant rehearses the item, but when an F cue is presented, the participant does not rehearse the item, likely using any available rehearsal time to rehearse earlier R items instead. The F items are not well rehearsed and therefore are not well encoded; as a result, F items are disadvantaged at test compared to R items. Even re-presentation of the item does not attenuate the effect (Basden et al., 1993).

In contrast, under the list method, the participant is not aware when (or even if) the F cue will be presented, therefore there is no motivation to delay rehearsal. Presumably all F items are rehearsed until the mid-list presentation of the F cue, at which point rehearsal of the F items ceases. Thus, under the list method, F items should be rehearsed and encoded to the same extent as R items. The theoretical consequence is that F-R recall differences at test cannot be attributed to selective rehearsal of R items, given that all items are rehearsed. Instead, Bjork (1989) proposed that list method directed forgetting effects resulted from inhibition. Upon presentation of the F cue, the F set is inhibited and these items consequently are disadvantaged at recall. Re-presenting the item at retrieval releases the inhibition such that the F items, which were encoded and are stored in memory, become accessible again (Basden et al., 1993).

This account also nicely handles the "standard" finding that a directed forgetting effect is observed on a recognition test only for the item method. Under the item method, F items are poorly learned, which should be evident on any (explicit) memory test. But under the list method, the representation required to test recognition releases the inhibition, eliminating any effect on recognition. This is precisely what the data of numerous studies had demonstrated—that there was little if any directed forgetting effect on recognition using the list method (see MacLeod, 1998, for a review).

The release from inhibition distinction between list method and item method directed forgetting is crucial. This dichotomy provides the best evidence that different mechanisms underlie the two methods. If words can be retrieved under some test conditions (e.g., recognition), this implies that the items were encoded and learned; if the items cannot be retrieved under any test condition, this implies that the items were not encoded and learned. The idea that different mechanisms underlie list method and item method directed forgetting is now the most widely subscribed theoretical account of directed forgetting (MacLeod, 1998).

The role of selective rehearsal in item method directed forgetting is the commonly accepted and seemingly sufficient explanation of item method directed forgetting (Johnson, 1994; MacLeod, 1998). Recently, however, the inhibitory view of list method directed forgetting has begun to be challenged. Sahakyan and colleagues (e.g. Sahakyan & Delaney, 2003; Sahakyan & Kelley, 2002) and MacLeod, Sheard and colleagues (e.g., MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003; Sheard, Dodd, Wilson, & MacLeod, 2004; Sheard & MacLeod, 2002) have proposed alternatives to the inhibition-based explanation of list method directed forgetting.

Sahakyan and Kelley (2002) introduced a *context change account* of list method directed forgetting. Upon presentation of an F cue, participants actively try to forget the preceding items by changing their internal context (e.g., their state or mood) so that they are in a different internal context during presentation of the R list. At retrieval, they remain in this second context which facilitates recall of R items but impedes recall of F items because they were encoded under a different context. The mismatch between the encoding and retrieval contexts of F items results in impaired recall of F items, much like state dependency affects memory in drug studies (see, e.g., Eich, 1980). Their results were consistent with this view in that a context change even in the absence of an F cue impaired recall of the first sub-list, and reinstatement at test of a context consistent with the encoding context (for F items) reduced the overall directed forgetting effect (Sahakyan & Kelley, 2002).

The context change idea is reminiscent of the early set differentiation and selective search concepts (see Epstein, 1972; see also Bjork, 1972, for reviews), although context change does provide a more process-based mechanism for set differentiation. Under the context change account, each set—both the R items and the F items—is associated with a different internal context and thus the differing contexts serve to segregate the sets. Although the context change account does not rely on retrieval inhibition, it is not entirely incompatible with such a view: A change in context could form the basis for inhibition in that the context-mismatched items become the ones that are inhibited at retrieval.

Both context change and retrieval inhibition propose that directed forgetting is a phenomenon occurring at retrieval, which is where these mechanisms exert their influence. In contrast, we propose an account of list method directed forgetting that, like context change, does not rely on inhibitory mechanisms but, unlike context change and the dominant inhibition theory, emphasizes encoding over retrieval. Our proposal also is not new; rather, it seeks to re-establish selective rehearsal as the explanation for both list method and item method directed forgetting.

As part of ongoing research in our laboratory, our goal is to evaluate more thoroughly the role of selective rehearsal in list method directed forgetting. Bjork (1989) and Basden et al. (1993) provided what appeared to be compelling evidence that a two-mechanism explanation of directed forgetting most appropriately accounts for the divergent findings under list method and item method instructions. In so doing, they denied any influence of selective rehearsal in list method directed forgetting. We argue, however, that selective rehearsal plays a more dominant role in list method directed forgetting than is currently recognized. So, in contrast to the current two-theory explanations of the directed forgetting effect, we propose that a single explanation—selective rehearsal—can provide a unified theory for all directed forgetting effects.

Early Evidence for Selective Rehearsal

To fully understand the unified rehearsal explanation, we will begin by summarizing the early evidence for selective rehearsal. Interestingly, initial accounts of directed forgetting discounted selective rehearsal, in large part because it was thought that selective rehearsal could not operate under such rapid presentation conditions (Bjork et al., 1968; Brown, 1954; see also Geiselman & Bagheri, 1985). The tide soon shifted, however, and many early findings derived from both the item method and the list method were explained in terms of selective rehearsal, although selective search was a popular alternate explanation (MacLeod, 1998).

Woodward and Bjork (1971) provided early evidence for the role of selective rehearsal in item method directed forgetting. Even with a financial inducement to recall both the R and F items, participants still recalled comparatively few F items (see also Reitman, Malin, Bjork, & Higman, 1973). Woodward and Bjork hypothesized that subjects waited for the R or F cue before processing the item and therefore that the F items were not rehearsed at study and consequently could not be recalled at test, despite the cash incentive. In contrast, upon presentation of the R cue, the R items were rehearsed and therefore were considerably better recalled at test. Although along the way Woodward and Bjork considered both encoding and retrieval loci for selective rehearsal effects (Bjork & Woodward, 1973; Woodward & Bjork, 1971; see MacLeod, 1998, for a discussion), the basic tenets of their selective rehearsal account remain in place today in the explanation of item method directed forgetting. Participants delay rehearsal until a cue is presented: If the cue is an F cue, no rehearsal follows, but if the cue is an R cue, then the participant selectively rehearses the R item. The dominant role of rehearsal in item method directed forgetting was, therefore, established early on. Intriguingly, so was the role of selective rehearsal in list method directed forgetting.

As mentioned, the role of rehearsal in item method directed forgetting is not terribly controversial: The evidence for selective rehearsal is solid and rarely has a researcher actively contested this claim. The evidence for selective rehearsal in list method directed forgetting is more controversial, however, and over the years the evidence for or against the role of selective rehearsal has been inconsistent. In her review, Johnson (1994) indicated that selective rehearsal (or post-instruction encoding) could not account solely for, but could contribute to, list method directed forgetting effects. In this section, we will highlight the studies that support a selective rehearsal account of list method directed forgetting. Although the current inhibitory view of list method directed forgetting rejects an influence of selective rehearsal, there is a long history of evidence that counters this claim. Early research using list method instructions yielded many results consistent with a selective rehearsal account.

In 1970, Bjork examined the effect of a cue to forget previously learned words. On recall tests, the number of precue forget pairs did not impact recall of the R pairs whereas in lists with a “non-designated” cue (specifying neither F nor R), precue pairs did interfere with postcue pairs, with postcue word pair recall declining as the number of precue word pairs increased. Furthermore, the F-cued items were not well recalled—the classic directed forgetting effect. Bjork proposed that participants used the cues to segregate the lists and that they then selectively rehearsed the R items. Segregation and rehearsal were seen as symbiotic, with segregation allowing for selective rehearsal, and selective rehearsal solidifying segregation. Timmins (1973) dissociated segregation and rehearsal by demonstrating that a repeated F item is better recalled than any other items (unrepeated F items or R items). This finding is inconsistent with segregation: If the first occurrence of the to-be-repeated item is within the F set, then it should be segregated with the unrehearsed F items and recalled only as well as other F items. Therefore, the enhanced recall of repeated F items indicates that these items were not segregated with other F items and also that they benefited from additional rehearsal. Although the relation between segregation and rehearsal was not clear, the role of selective rehearsal in list method directed forgetting was becoming well established.

In the early directed forgetting literature, however, the teaming of segregation and selective search was often compared with the teaming of segregation and selective rehearsal. In comparing these two accounts, MacLeod's (1975) data also argued against a selective search mechanism. MacLeod found that the R-F difference persisted over long intervals (one and two weeks) because of R-F encoding differences at input. Presumably a selective search account would predict a diminishing directed forgetting effect over a long interval, as the set differentiation information is lost. Stability of the directed forgetting effect over time implies that the selective rehearsal of R items at encoding resulted in a long-term R-F advantage due to differential original learning.

This stability of the effect is important because, in an earlier review, Epstein (1972) asserted that selective search was key, even though some of his own work indicated that selective rehearsal was an important component of list method directed forgetting. For instance, Epstein and Wilder (1972) found that the directed forgetting effect was larger for unfilled intervals (which offered rehearsal opportunities) than for filled intervals. They acknowledged briefly that selective rehearsal might operate to enhance the selective search process, but selective rehearsal alone was not viewed as a crucial mechanism. Certainly, typical results reveal that tasks designed to prevent rehearsal have minimal to no impact on the directed forgetting effect (see Johnson, 1994, for a review), the implication being that if rehearsal opportunity does not influence recall then selective rehearsal is not a viable mechanism. The findings of Spector, Laughery, and Finkelman (1973), however, contest this claim: When the R or F cue preceded the rehearsal interval, the directed forgetting effect was obtained, but when the cue followed the rehearsal interval, the directed forgetting effect vanished. Again we see that selective rehearsal findings in list method directed forgetting are not consistent.

By the late 1970s, support for the rehearsal account seemed to be losing ground (MacLeod, 1998). In early sentence-based item method work, Geiselman's results supported a selective rehearsal view (e.g., Geiselman, 1974; 1975); indeed subjective reports of rehearsal by participants further supported the rehearsal account (Geiselman, 1974). But a subsequent series of studies by Geiselman and colleagues (e.g., Geiselman, 1974; Geiselman & Bagheri, 1985) seemed to counter a rehearsal account. The crucial study in shifting the emphasis from encoding to retrieval was Bjork and Geiselman's (1978) modified item method study. By forcing retrieval of F items during recall ("What was that item you were told to forget?"), the directed forgetting effect was reduced in recall and eliminated in recognition, a finding seen as inconsistent with an encoding/rehearsal account of directed forgetting. Converging evidence came from a study by Geiselman, Bjork, and Fishman (1983) using a modified list method procedure. The R-F difference persisted for both intentionally and incidentally learned items, despite the fact that under a rehearsal account incidentally learned items should have no real advantage regardless of instruction because even given an R cue the incidentally learned words should not be rehearsed.

As an interesting aside, one of the seminal studies in propelling the inhibition view actually used the item method, now closely linked to selective rehearsal, the very mechanism that this study helped to undermine. Using the item method, Geiselman and Bagheri (1985) showed that item repetition benefited F items to a greater extent than R items; indeed, even unrepeated F items from a partially repeated set benefited from repetition. The hypothesis was that repeating some F items released the inhibition on previously unrecallable F items, much the same way that re-presentation is now thought to release the inhibition of F items. R items did not benefit as much from repeated presentation because they were never inhibited in the first place.

A series of follow-up studies (Geiselman & Panting, 1985; Geiselman, Rabow, Wachtel, & MacKinnon, 1985; for a review see MacLeod, 1998) led to a more general conclusion implicating both rehearsal and inhibition. This merged view suggested that selective rehearsal at encoding favored R items but that inhibition at retrieval impaired F items. It was the combined effect of these two different processes at two different sites that was responsible for the directed forgetting effect. Geiselman's two-process interpretation was later thought to be related to the as yet unidentified differences between list method and item method directed forgetting, however it is possible that his encoding-retrieval dual mechanism unified view might still be plausible.

The rehearsal-inhibition controversy continued until Bjork (1989) and Basden et al. (1993) seemingly solved the theoretical riddle. A selective rehearsal account evidently best accounts for the item method results, whereas a retrieval inhibition account evidently provides the best explanation of list method results. In particular, the presence of an effect on recognition under the item method and its absence under the list method seems diagnostic: Recognition is sensitive to reduced rehearsal (item method) but the re-presentation of the items required by a recognition test "disinhibits" F items, restoring their equivalence to R items (list method). Indeed, in many instances, list method results seem incompatible with a selective rehearsal account and item method results seem incompatible with an inhibition account.

It may be, however, that the two explanations have become too polarized over the past decade. Specifically, it is not clear that inhibition is the only or best explanation of list method directed forgetting (see MacLeod et al., 2003) or that a selective rehearsal account cannot provide a successful account of list method directed forgetting. Although the two methods-two mechanisms idea is appealing, we think that a selective rehearsal account of list method directed forgetting may have been abandoned prematurely. Certainly, in the vein of Geiselman, it seems reasonable that at the very least both inhibition and selective retrieval operate in list method directed forgetting but, to reach further, it is possible that selective rehearsal alone can account for list method directed forgetting findings. If so, the principle of parsimony would be well-served by having a unified account of directed forgetting.

New Evidence For a Rehearsal Account of List Method Directed Forgetting

We have already sketched our argument that an inhibitory account of list method directed forgetting may not be necessary or appropriate, and that a selective rehearsal explanation may be entirely satisfactory (see MacLeod et al., 2003). Ongoing list method research in our laboratory certainly suggests that rehearsal does play a role in list method directed forgetting, implying that longstanding and well defined memory operations can account for the directed forgetting effect without reliance on what we see as less well defined notions of inhibition. In the first series of experiments, we show that rehearsal opportunities during a pretest delay greatly impact the directed forgetting effect, implying that rehearsal is a factor in list method directed forgetting, at least under delay conditions. In the second series of experiments, we dissect the recall pattern of a typical directed forgetting study using a serial position analysis. Clear—and quite classic—rehearsal patterns emerge. Taken together, these results indicate to us that rehearsal does play a role—a substantial role—in list method directed forgetting.

The Delayed Recall Project

In the first series of studies (Sheard, Dodd, Wilson, & MacLeod, 2004) we investigated selective rehearsal in list method directed forgetting using a delay variant of the paradigm. Basden and Basden (1998; see also Gilliland, McLaughlin, Wright, Basden, & Basden, 1996) developed a paradigm to investigate the effects of a pre-delay recall warning on directed forgetting. They reported that a pre-delay warning telling the participant that in fact both R and F items will have to be recalled eliminates the directed forgetting effect under list method conditions (but not under the item method). Their explanation is that under the list method participants normally adopt a retrieval strategy that inhibits the F items and emphasizes the R items, but that a warning prior to a delay provides an opportunity for the participants to switch retrieval strategies and more equally emphasize R and F items (see MacLeod et al., 2003, for a critique of the inhibition explanation). However, the delay results are not incompatible with a selective rehearsal account. Clearly, the delay also provides an opportunity for selective rehearsal and, following a warning, participants might simply switch rehearsal strategies to emphasize the previously neglected F items. We sought to evaluate this possibility.

Under a selective rehearsal assumption, if a delay is preceded by a warning that the participants will have to recall both the F and the R items (the *delay-warning* condition), then the interval could be used to selectively rehearse F items, a shift in emphasis presumed to reflect the perceived difficulty that will be experienced in trying to recall the F items after all. Consequently, R items will not be as well rehearsed as they would be if the delay were not preceded by a warning (the *delay–no warning* condition), where participants would presumably focus rehearsal on the R items, assuming (consistent with initial instructions) that only the R items will be tested. Because it is also likely that rehearsal strategies would differ between participants, we divided the participants into high and low memory groups based on overall memory performance. High memory participants probably utilize better rehearsal strategies than do low memory participants, and so the warning manipulation should differentially affect the two groups. All results were compared to a standard directed forgetting condition in which there was no delay between the study and test sessions (the *no delay* condition).

Figure 1 shows the data from the first experiment in this project. The delay-warning and delay-no warning low memory groups showed equivalent directed forgetting. Apparently, low memory participants did not use the delay to strategically rehearse either R or F items. Indeed, a comparison between the delay conditions and the no delay condition is telling:

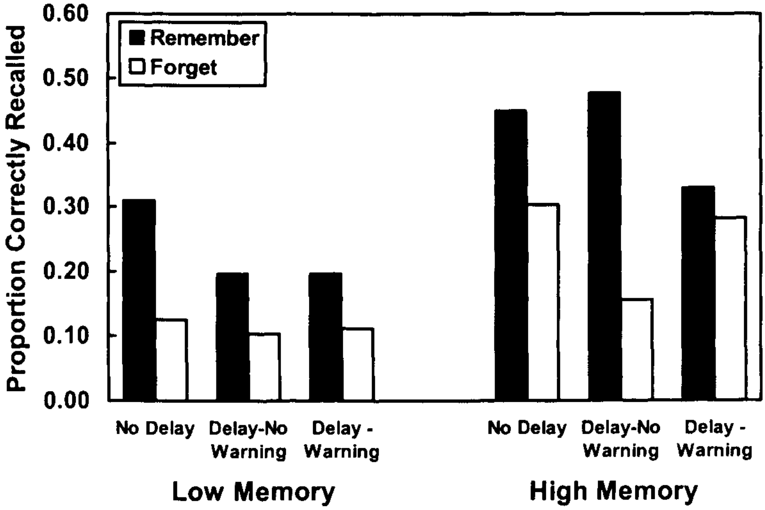

Fig. 1. The effect of a pre-delay warning that both R and F items are to be recalled (delay – warning), no pre-delay warning regarding recall (delay – no warning), or no delay (no delay) on directed forgetting, for both high and low memory participants.

Under the no delay condition, participants recalled significantly more R items than under either delay condition, but the groups did not differ at all in recall of the F items. The loss of R items over the delay suggests that the low memory participants were not rehearsing at all during the study-test interval, and that they simply forgot some of the R items over the delay.

In contrast, the high memory participants did show a marked effect of warning. In the standard no delay condition, a significant directed forgetting effect was found. Under the delay-no warning condition, however, the size of the directed forgetting effect increased substantially due to increased recall of R items and decreased recall of F items, relative to the no delay condition. This pattern implies that, without a warning, high memory participants were actively rehearsing the R items during the delay, to the detriment of the F items. Rehearsing R items is a strategic way of maximizing recall given that the participant believes that only R items will be tested. The pattern reversed for the delay-warning condition: The directed forgetting effect disappeared, the result of decreased recall of R items and stable recall of F items over the delay interval. Again, the results are consistent with a rehearsal-based explanation. When warned,

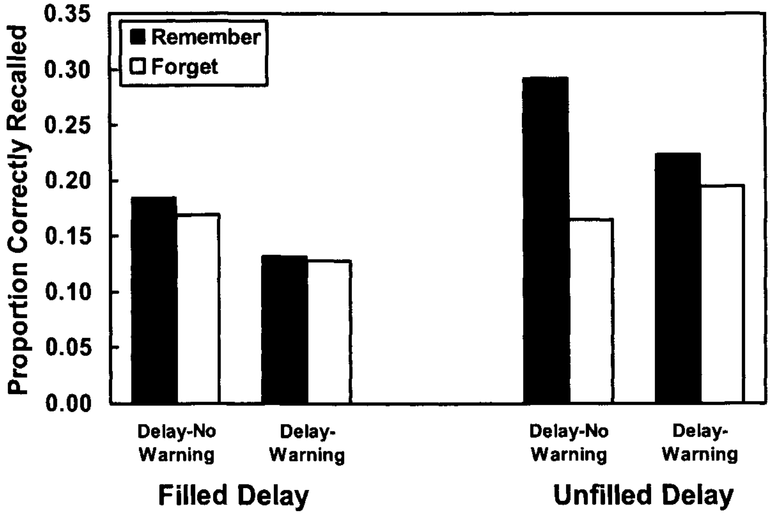

Fig. 2. The effect of a filled versus unfilled delay as a function of warning on directed forgetting.

high memory participants strategically rehearsed F items over the delay, successfully maintaining their level of recall (which had suffered with no warning). But this benefit for F items came at the cost of a significant reduction in the recall of R items, attributable to emphasis on the F items, which were seen as in greater need of rehearsal.

In Experiment 2, we further explored the role of selective rehearsal in the warning effect paradigm. To focus on the differences between "rehearsers" vs "non-rehearsers," we directly manipulated rehearsal opportunities during the delay. In the *filled delay* condition, the participants were engaged in an effortful spatial task designed to prevent rehearsal. In the *unfilled delay* condition, we provided motivation to rehearse, telling participants prior to the delay that they would receive payment for each item correctly recalled. We expected performance in the filled delay condition to mirror that of the low memory participants from Experiment 1 and performance in the rehearsal condition to mirror that of the high memory participants.

The findings supported the predictions (see Figure 2). The filled groups did not show an effect of the warning manipulation nor was there a significant directed forgetting effect. Inability to rehearse over the delay resulted in a loss of R; recall of the F items was too poor to demonstrate any significant loss over the delay. The unfilled groups, who had the chance (and incentive) to rehearse, revealed a significant directed forgetting effect in the delay-no warning condition, but no directed forgetting effect in the delay-warning condition. The difference stemmed from recall of R items: The delay-no warning group recalled more R items than did the delay-warning group. With no warning that F items must also be recalled, the delay was used for continued rehearsal of the R items, resulting in a larger than normal directed forgetting effect.

In combination, these results provide support for the role of selective rehearsal in list method directed forgetting, at least under delay conditions. Is it also reasonable to assume that participants might utilize rehearsal strategies under typical no delay conditions as well? That was the goal of the next series of experiments (Sheard & MacLeod, 2002), in which we provide evidence of selective rehearsal under standard no delay list method directed forgetting conditions.

The Serial Position Project

In a second series of ongoing studies (Sheard & MacLeod, 2002; a preliminary sketch of the studies was reported in MacLeod et al., 2003), we further investigated the possible role of selective rehearsal in list method directed forgetting by analyzing the serial position curves for the R and F sub-lists. Serial position differences are the hallmark of rehearsal effects in recall (Rundus, 1971; Rundus & Atkinson, 1970), and thereby clearly expected under a rehearsal explanation. If rehearsal does play a central role in list method directed forgetting, then recall differences in F and R might reasonably be expected to vary by serial position. Our basic idea is that the directed forgetting effect stems not from the poorer overall recall of the F items that would be anticipated based on the idea that all F items are inhibited (see Geiselman et al., 1983), but rather from the differential recall of R and F items located in the primacy and recency portions of the two sub-lists. If, as the inhibition account would have it, the F sub-list is rehearsed to the same extent as the R sub-list but is then subsequently inhibited, we see no reason not to expect consistent R and F patterns for serial position. Nothing in the current inhibition account would seem to provide a principled basis for serial position differences between the F and R items, unlike the case of selective rehearsal.

In our first study (Sheard & MacLeod, 2002), we replicated the within-subject list method design, comparing recall of the initial F sub-list (List 1) to that of the subsequent R sub-list (List 2), following what has become common practice in the literature. We obtained the typical directed forgetting effect: Recall of the R sub-list was significantly better than recall of

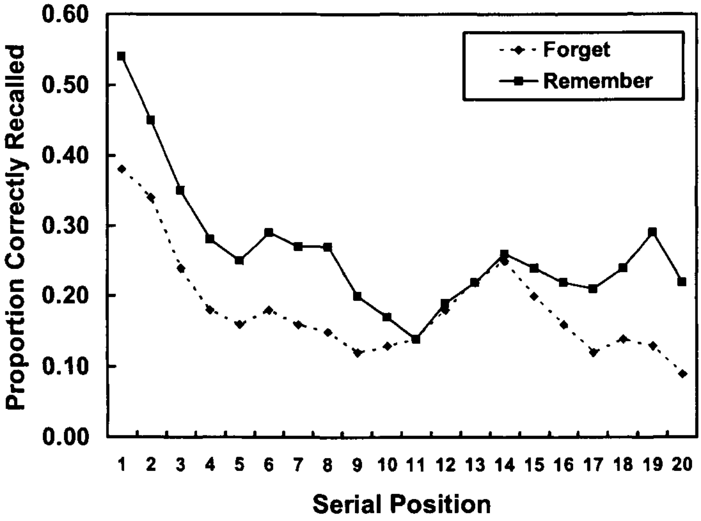

Fig. 3. Serial position effects for Forget (list one) versus Remember (list two). The differences in recall stem from differences in the primacy and recency portions of the curve: The Remember list shows a marked primacy and recency effect compared to the Forget list, which shows only a modest primacy and no recency effect. All curves shown are smoothed by using an algorithm that averages the data point with the two adjacent data points (e.g., position 15 represents an average of position 14, 15, and 16).

the F sub-list. But the serial position analysis revealed an interesting pattern underlying this R-F difference. It was not recall of the entire F list that was reduced in comparison to the R list, contrary to what might be anticipated from an unadorned inhibition explanation. Rather, the differences in recall were restricted to the primacy and recency portions of the curve, with the R list showing a marked primacy and recency effect compared to the F list, which showed a more modest primacy effect and no recency effect. This pattern is displayed in Figure 3.

This serial position pattern is inconsistent with the classic inhibition view that the entire F list is inhibited at retrieval (e.g., Basden & Basden, 1998). To explain our serial position pattern, one must argue that inhibition is selective and that items are inhibited to varying degrees—in a pattern consistent with a rehearsal account (see MacLeod et al., 2003). Indeed the findings are much more consistent with a selective rehearsal account. Upon presentation of the F cue, the participant devotes extra attention to the first few words of the subsequent remember list, resulting in a marked primacy effect for the R sub-list (List 2). Add to this the expected recency effect for the second sub-list, and we see an overall difference in recall favoring the R sub-list over the F sub-list. But the resulting "directed forgetting effect" is an illusion: The F sub-list was not forgotten, rather the R sub-list was better remembered because of privileged rehearsal of the first few items and working memory access of the last few items.

In Experiment 2 we removed the within-subject design order confound in which the F sub-list precedes the R sub-list to which it is compared. We added two control conditions. The first was the standard R-R control condition, which would permit us to compare F recall and R recall for the first sub-list between subjects, avoiding the order confound that is intrinsic to the within-subject design. The second additional control condition was a variation of the standard R-R control condition where the participant was explicitly instructed to stop rehearsing the first R sub-list following the cue. This was intended to more closely mimic the F-R condition, at least according to the selective rehearsal account. The idea is that, upon receipt of a F cue, the participant presumably discontinues rehearsal of the first (F) sub-list; however, if the first sub-list is followed by a R cue, the participant may be inclined to continue rehearsing that first sub-list. To properly compare a F List 1 to a R List 1, then, we incorporated a R List 1 condition in which participants were also encouraged to stop rehearsal upon receipt of the cue, analogous to the forget condition. As it turned out, these two control groups did not differ, so we will describe only the results from the standard R-R group.

In comparing List 1 (F) from the F-R group to List 1 (R) from the R-R group, we found no reliable differences. Both overall recall and the serial position curves were comparable, as can be seen in Figure 4. An inhibitory account would predict that recall of the F List 1 should be reduced compared to recall of the R List 1, but it was not—there was no directed forgetting effect. This may seem surprising, given that previous studies have reported such a difference (e.g. Liu, Bjork, & Wickens, 1999; Reitman et al., 1973; Sahakyan & Kelley, 2002). Only using the order-confounded within-subject comparison was a directed forgetting effect present; using the more appropriate between subjects design, there was no such effect.

Further analysis of List 2 (R) from the F-R group vs List 2 (R) from the R-R group was also quite informative. On List 2 (the R sub-list), the F-R group revealed a marked primacy effect, in contrast to the R-R group, which showed no primacy effect at all. This pattern is clearly evident in Figure 5. When a R sub-list follows a F sub-list, there is a dramatic influence on primacy; however, a R sub-list following a R sub-list displays no primacy advantage at all. It follows, then, that a mid-list F instruction influences the participant's subsequent behavior. Specifically, as noted in

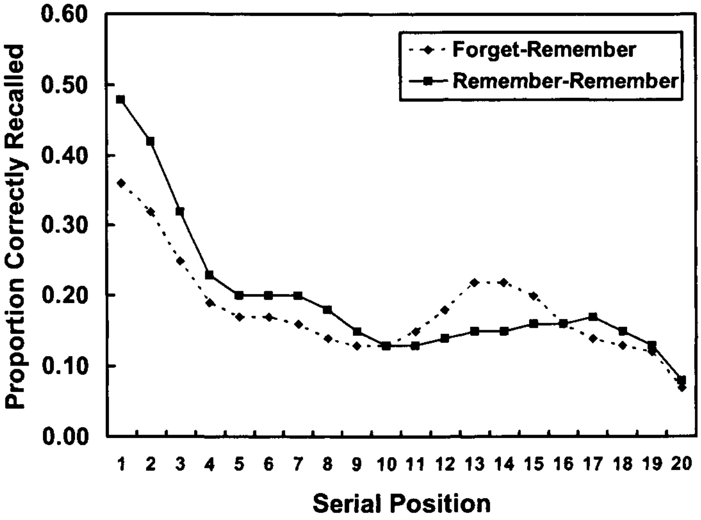

Fig. 4. Forget (list one) from a Forget-Remember condition versus Remember (list one) from a standard Remember-Remember condition. There were no significant differences between groups in recall of list one—that is, using this measure, there was no directed forgetting effect.

Experiment 1, participants actively rehearse the initial items of the R sub-list. This behavior is not a general List 2 phenomenon because when a R sub-list follows another R sub-list, there is no extra rehearsal of the second sub-list. More likely, following a mid-list R instruction for the preceding sub-list, the participants continue to rehearse the first sub-list to the detriment of the first few items on the second sub-list, but to the overall advantage of List 1 compared to List 2. Indeed, with the continued rehearsal of List 1, we would expect better overall recall of a R List 1 compared to a R List 2. As it happens, this finding is both typical in the literature (Bjork, 1970; Liu et al., 1999; Sahakyan & Kelley, 2002) and replicated in this study.

The serial position analyses indicate that participants adopt a different rehearsal strategy for List 2 following a F cue than following a R cue. The difference in recall in a within-subject comparison results from the effect of the F cue on the subsequent R sub-list and not from inhibition of the initial F sub-list. Again, we see that there is a highly probable role for a selective rehearsal strategy in list method directed forgetting.

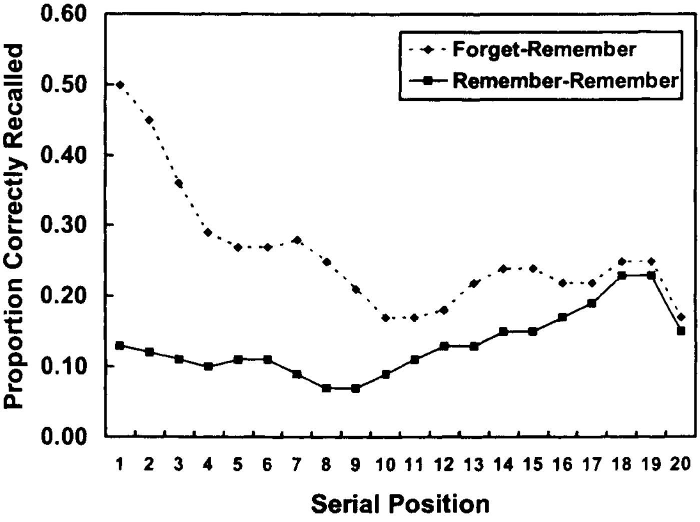

Fig. 5. Remember (list two) from a Forget-Remember condition versus Remember (list two) from a standard Remember-Remember condition. There is a marked difference in recall of list two—when list two follows a forget instruction, it benefits from a strong primacy effect not found when list two follows another remember list.

Although we see these results as compelling, the astute reader might note that we have yet to explain the absence of a list method directed forgetting effect on a recognition test, in contrast to the clear directed forgetting effect in recognition under item method instructions. Although we have not yet tested our hypotheses empirically, we offer two possible reasons. First, we speculate (see MacLeod et al., 2003) that at least part of the method difference in recognition hinges on the initial differences in effect size. The directed forgetting effect on recall ordinarily is considerably larger under the item method than the list method (see, e.g., Basden, et al., 1993; MacLeod, 1999). Under the item method, to the extent that one can compare recall and recognition directly, the directed forgetting effect diminishes from recall to recognition. If the effect also diminishes from recall to recognition under the list method, it may actually disappear. Put simply, the effect disappears under the list method because the starting effect size is so much smaller that it reaches the floor.

Our second possibility for why there is no directed forgetting effect on recognition under the list method relates to our serial position findings. There is evidence that recognition may not show serial position effects as strongly as recall (see, e.g., Cohen, 1970; Kintsch, 1968), therefore if the list method directed forgetting effects in recall are serial position effects they may not be observable in recognition. Note that under neither of these speculated mechanisms is it necessary to posit an inhibitory mechanism to account for the "release from inhibition" finding of no directed forgetting in recognition under the list method. One focus of current research in our laboratory is investigating conditions under which re-presentation does and does not result in the "release from inhibition" pattern. We also intend to test the floor effect possibility by finding ways to increase the size of the directed forgetting effect in list method recall; if we are right, this might then leave room for a directed forgetting effect to be observed in a corresponding list method recognition test.

Inhibition, as the term is currently used, is a very broad and flexible concept, as we have discussed elsewhere (MacLeod et al., 2003), and as Anderson (this volume) clearly illustrates. It would therefore quite likely be possible to construct a version of an inhibition account that could handle the results that we have just presented, but we believe that such an account would involve what would essentially be selective rehearsal mechanisms in disguise. We can think of no way to definitively refute the idea that inhibition is involved in list method directed forgetting, at least not without a better specified inhibition theory. What we can say is that there now appears to be converging evidence from our laboratory that selective rehearsal plays a central role in list method directed forgetting.

Other Evidence Supporting a Selective Rehearsal Account

There is evidence favoring a selective rehearsal account of list method directed forgetting from other laboratories as well. We will cite two other relevant projects. Kimball and Metcalfe (2001) pursued the approach introduced by Geiselman et al. (1983). In that study, participants were to learn one set of alternating words intentionally, with the other set of alternating words being learned incidentally (pleasantness judgment). Because there should have been no reason to rehearse the incidentally studied words, selective rehearsal should not have operated on these items. Therefore, directed forgetting should have occurred only for the intentionally learned items. But Geiselman et al. found directed forgetting for both sets of items, a pattern that they saw as inconsistent with selective rehearsal but consistent with intentional suppression of the entire F sub-list, which they assumed to be a single episode.

The Geiselman et al. (1983) study is one of the key early pieces of evidence cited as favoring an inhibition account of list method directed forgetting. Kimball and Metcalfe (2001) replicated this study with five modifications aimed at minimizing possible formation of associations between the intentional and incidental items, and at reducing the likelihood of such pre-experimental associations being used at the time of recall. What they observed was very different from what Geiselman et al. (1983) had found: There was a directed forgetting effect on recall for the intentional condition but not for the incidental condition. Consequently, following the logic of Geiselman et al., Kimball and Metcalfe's results supported the selective rehearsal account, not the retrieval inhibition account.

Recently, Golding and Gottlob (in press) explored the effect of recall order on list method directed forgetting, a factor which Geiselman et al. (1983) had claimed was not influential. In Experiment 1, Golding and Gottlob first demonstrated that, left to their own devices, participants tended to recall the R (second) sub-list before the F (first) sub-list. When Golding and Gottlob then forced the order to be either R then F or F then R in Experiments 2 and 3, they found a directed forgetting effect only for the R-then-F order, consistent with the preference pattern in Experiment 1. They saw this pattern as inconsistent with an inhibition account, and more consistent with a retrieval strategy favoring priority in recall of the more recent R items. We simply note that it is possible that this preference results from subjects recalling first what they are currently rehearsing, which would help to mesh the Golding and Gottlob finding with a selective rehearsal explanation.

There is other recent research to support the selective rehearsal explanation of list method directed forgetting. Using a post-experimental questionnaire, Whetstone, Cross, and Whetstone (1996) found that considerably more of the participants in the R condition reported selective rehearsal in terms of thinking about List 1 while studying List 2 than did F participants. Conway, Harries, Noyes, Racsma'ny, and Frankish (2000) found that the directed forgetting effect was reduced and could even be eliminated with a sufficient memory load during List 2 processing. This is consistent with a selective rehearsal account if we assume, quite reasonably, that the higher memory load prevented rehearsal. They also showed that the directed forgetting effect was eliminated if there was sufficient semantic relatedness between the F and R sub-lists. Similar to the argument of Kimball and Metcalfe (2001), semantic associations between the two sub-lists could lead participants to rehearse items across the two sub-lists rather than selectively rehearsing List 2 items.

Conclusions

In this chapter, we have considered the various accounts that have been provided over the past 35 years or so for the phenomenon of directed forgetting, which provides an experimental analogue to the everyday updating of memory. Two rise above all others: selective rehearsal and retrieval inhibition. It is clear to virtually all investigators (see MacLeod, 1998, for a review) that, for the item method of directed forgetting where each item receives its own instruction, selective rehearsal is the mechanism that underlies the advantage of R items over F items. Participants hold each item in abeyance until its instruction appears, and then they only rehearse R items. The theoretical debate, then, concerns the list method, where one sub-list is designated F and the other sub-list is designated R, such that multiple items receive the same instruction simultaneously.

The retrieval inhibition account is presently the dominant explanation of list method directed forgetting (see discussion in MacLeod, 1998; MacLeod et al., 2003), maintaining that the entire F sub-list is suppressed, and hence less likely to be retrieved at the time of test. Consistent with our broader concern regarding inhibitory mechanisms in attention and memory (see MacLeod et al., 2003), we have questioned whether list method directed forgetting might also be successfully explained using a selective rehearsal account. Toward that end, we have presented evidence from two lines of work in our laboratory as well as additional work from other laboratories that is inconsistent with an inhibition explanation and quite consistent with a selective rehearsal explanation.

The implications of a unified selective rehearsal account are interesting. Johnson (1994) argued that item method directed forgetting is not directed forgetting at all, but merely directed—hence selective—rehearsal or learning. She further argued that list method directed forgetting is true directed forgetting because the information is learned before the instruction, such that impaired recall reflects true forgetting and not just differences in learning. Based on Johnson's criterion, our proposal that list method directed forgetting is also due to selective rehearsal implies that there is no true directed forgetting! We see this as the wrong conclusion, however, and believe that both methods of delivering instructions to forget can be informative about how we update our memories. That this updating appears to rely heavily on selective rehearsal does not surprise or disappoint us—it is indeed reminiscent of the argument that "flashbulb" memories are well remembered not because of their special emotional nature but because they are rehearsed more often (see, e.g., McCloskey, 1992; Shum, 1998). Selective rehearsal is undoubtedly among our most fundamental memory abilities.

Author notes

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Conscious and Unconscious Processes in Hypermnesia

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Summary. Memory performance changes as a function of repeated testing even when we are not re-exposed to the to-be-remembered material between tests. Our research has focused on whether recovery of previously unretrieved items on a subsequent test—referred to as reminiscence—is based on conscious or unconscious processes. There is ample evidence indicating that reminiscence requires active searches of memory (i.e., conscious process). However, subjective experiences suggest that previously unretrieved items sometime pop into mind without an active search of memory (i.e., unconscious process). In line with this hypothesis, studies have shown that (1) tip-of–the-tongue experiences are often resolved when the sought-after information pops into mind; (2) participants often have no knowledge of items prior to recovering these items; and (3) unlike recall, older adults show similar levels of reminiscence as do young adults. However, when one compares data from explicit and implicit memory tests, the explicit test produces greater amounts of reminiscence than the implicit test, even though reminiscence is also present in the implicit memory test. Based on these results, we suggest that there are two types of reminiscence, voluntary and involuntary; the former requires conscious retrieval whereas the latter does not. The existence of these two types of reminiscence suggests that when retrieval attempts for sought-after information are repeated, memory performance is determined by the dynamic interplay between conscious and unconscious processes.

Key words. Repeated testing, reminiscence, hypermnesia, automatic processing, voluntary and involuntary reminiscence

Introduction

In many respects, single trial testing, which is the mainstay of traditional memory research, does not capture the essence of memorial processes in real world settings, where we are rarely limited to a single retrieval attempt. Further, rarely do we have the opportunity for repeated exposures to the to-be-remembered items between retrieval attempts. After all, these items are not known until they are successfully retrieved from memory, and once they are retrieved, we no longer need to repeat retrieval attempts. Consequently, repeated testing without re-exposure to study material is arguably the paradigm most suitable for studying the dynamic processes involved in memory retrieval.

What are the processes involved in repeated testing? The goal of repeated retrieval attempts is to recover from memory previously unrecalled items. Although we do not always succeed, when we do, we refer to this phenomenon as *reminiscence.* Reminiscence was first reported by Ballard (1913), who presented lines of a poem to children and tested their memory twice without re-exposing them to the poem between tests. Surprisingly, memory performance improved across the two tests. Ballard coined the term "reminiscence" to describe "the remembering again of the forgotten without re-learning" (p. 1).

A second process works in the opposite direction. When we repeatedly attempt to retrieve a number of items, some items are inevitably lost, a phenomenon referred to as *intertest forgetting.* Intertest forgetting works together with reminiscence to determine how memory performance changes across repeated tests. If intertest forgetting exceeds reminiscence, there would be a net loss in memory performance across repeated tests (this would simply appear to be forgetting.) If reminiscence exceeds intertest forgetting, there would be a net gain in memory performance across tests. Such an increase in memory performance across tests has been referred to as *hypermnesia.*

The modern investigation of hypermnesia was initiated by Erdelyi and Becker (1974). These researchers asked participants to study a list of words and pictures, which were then followed by three forced free recall tests. They found that performance increased across repeated tests for pictures but not for words. Further, the increase was not based on a shift in response criteria across tests (e.g., participants became less conservative in reporting items on a repeated test) because participants were forced to produce a fixed number of responses on each test. This latter finding is particularly important because it suggests that hypermnesia is not an artifact of participants becoming more willing to report previously unsure items when a test is repeated. Thus, it appears that without further study, memory really can improve across successive tests.

Since Erdelyi and Becker's (1974) investigation, numerous studies have shown that hypermnesia occurs in a variety of conditions (see Erdelyi, 1996; Payne, 1987, for reviews). A critical research issue has been identification of the mechanisms responsible for the effect. In our laboratories, we have focused on identifying the mechanism(s) responsible for reminiscence (rather than intertest forgetting) because although hypermnesia is a result of both reminiscence and intertest forgetting, without reminiscence, memory performance would not increase across repeated tests. The principal issue that we have been pursuing is the extent to which reminiscence is the product of conscious versus unconscious processes. That is, does the recovery of a previously unrecalled item require conscious (i.e., effortful) searches or can recovery occur without conscious retrieval attempts? In this chapter, we review data that speak to this question.

Reminiscence is the Product of Conscious Searches

There is ample evidence to suggest that conscious memory searches are responsible for reminiscence and hypermnesia. To begin with, hypermnesia has been demonstrated primarily with free recall tests (see Erdelyi, 1996; Payne, 1987), tests that are heavily dependent on active memory searches. In contrast, only a few studies have shown hypermnesia with recognition tests (e.g., Erdelyi & Stein, 1981; Groninger & Murray, 2004). However, these studies relied on non-standard recognition paradigms that likely emphasized active searches. For example, Erdelyi and Stein (1981) presented a list of cartoons with verbal captions that either matched (i.e., were funny) or did not match (i.e., were not funny) the pictures. Their recognition tests consisted of either pictures or verbal captions, and participants were asked to make yes/no decisions. Their results indicated that *d'* increased across three tests for the funny pictures (i.e., those with funny captions at study) and no increase was observed for the non-funny pictures (i.e., those with captions that were not funny) nor for the verbal captions alone.

Erdelyi and Stein explained their results by assuming that recognition, like recall, requires two stages: first generating candidates and then recognizing which of the generated candidates were actually studied items. Further, according to these authors, performance increases across tests only when "retrieval operations are non-trivial" (p. 31). They argued that because pictures and captions were highly associated in the case of the funny pictures, participants could make these pictures recognizable by actively retrieving their captions. These researchers further hypothesized that performance did not increase across tests for the non-funny pictures and for the captions because recognition of these items required little active retrieval (i.e., recognition was essentially automatic).

Similarly, Groninger and Murray (2004) observed recognition hypermnesia because their paradigm also emphasized an active search. They conducted two experiments using a face-name paradigm where participants were presented with a video of people introducing themselves using assigned names. During the tests, participants viewed the faces once more and selected the correct names among the alternatives. What was unique about this test was that for each face, the alternatives were the names of all 20 individuals who appeared in the videotape plus four distractor names. Consequently, for each face, participants could not simply select the most familiar name among the distractors; instead, they had to search for an association between a particular face and a particular name. Their research revealed reminiscence as well as hypermnesia. Groninger and Murray explained their results based on the notion of redintegration. That is, the names on the first tests may have initiated memory searches that resulted in the activation of appropriate faces. Clearly, these researchers considered active searches an essential component of finding reminiscence and hypermnesia in recognition.

It is notable that both Erdelyi and Stein (1981) and Groninger and Murray (2004) used pictorial stimuli. This raises a question as to whether it was the use of pictorial stimuli or the emphasis on active searches (or perhaps, an interaction of these two factors) that accounted for their observation of reminiscence and hypermnesia in recognition. After all, the earliest theory of hypermnesia considered pictorial encoding a critical factor in producing the phenomenon (e.g., Erdelyi & Becker, 1974; Erdelyi, Finkelstein, Herrell, Miller, & Thomas, 1976).

In an effort to determine whether pictorial stimuli are necessary to observe hypermnesia in recognition, we (Otani, Widner, & Kato, 2001) attempted to replicate Groninger and Murray's (2004) results using words rather than faces as the study material. In the first experiment, we presented 20 pairs of unrelated words and asked participants to learn these pairs under one of two conditions: the incidental learning condition where participants were asked to create the images of each pair or the intentional learning condition where participants were asked to learn the pairs for a subsequent unspecified memory test. Participants were then asked to perform a two-minute filler task followed by two five-minute recognition tests. In accordance with Groninger and Murray, for the recognition tests, we presented the cue words plus all of the target words and four distractor words.

Our results are shown in Figure 1. We determined reminiscence by counting the number of items that were correctly recognized on the second test that were not recognized on the first test whereas we determined intertest forgetting by counting the items that were correctly recognized on the first test that were not recognized on the second test. The results of Experiment 1 indicated that overall performance did not increase across tests for either encoding condition (i.e., there was no hypermnesia) because reminiscence failed to exceed intertest forgetting. Accordingly, in the second experiment, we attempted to increase reminiscence by inducing elaborative processing at encoding because, as we describe below, elaboration is an integral part of hypermnesia. We hypothesized that an active memory search would result in the retrieval of additional items when participants elaborated the study material at encoding. To induce elaboration, we asked participants to create a sentence using both the cue and target. Additionally, we increased the number of pairs from 20 to 36 in an effort to avoid any possible ceiling effect. As can be seen in Figure 2, memory performance increased across tests, indicating that reminiscence exceeded intertest forgetting, resulting in hypermnesia.

Our data support the assertion that the use of pictorial stimuli is not necessary to obtain reminiscence and hypermnesia in recognition. Rather, what appears to be an important variable is an active search (i.e., not simply recognizing information based on familiarity) during retrieval attempts at test. In contrast, when a standard recognition paradigm is used, hypermnesia is not observed because these tests do not emphasize active searches (Otani & Hodge, 1991; Otani & Stimson, 1994; Payne & Roediger, 1987). For example, in both Otani and Hodge (1991) and Otani and Stimson (1994), participants were asked to perform encoding tasks that were designed to induce relational and item-specific processing. The hypothesis was that item-specific processing would produce hypermnesia in recognition because item-specific processing would increase the level of distinctiveness for each item, and this would facilitate recognition performance. In contrast, relational processing would not produce recognition hypermnesia because elaborating inter-connections among study items would not facilitate recognition performance (see Hunt & Einstein, 1981). The results of both studies revealed that neither item-specific processing nor relational processing resulted in hypermnesia in recognition. Although there was a small amount of reminiscence, it was not large enough to exceed intertest forgetting. Taken together, these earlier data, combined with the new data just described, suggest that the only way to increase reminiscence in recognition is to use tests that emphasize active searches of memory (i.e., that promote conscious processes).

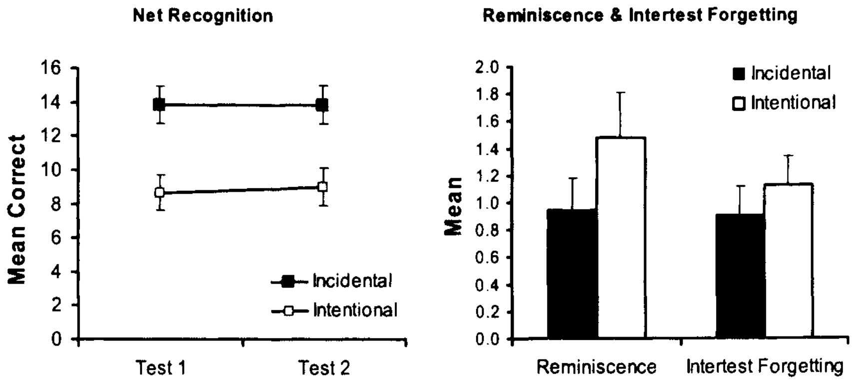

Fig. 1. Mean correct items as a function of encoding condition and test (left) and mean reminisced and forgotten items as a function of encoding condition (right).

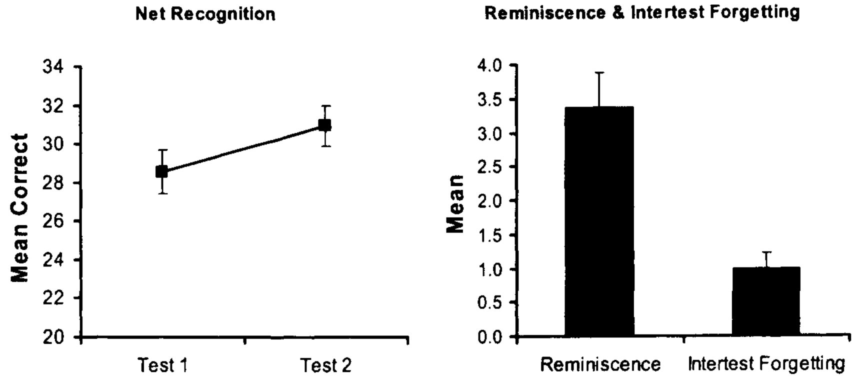

Fig. 2. Mean correct items across two tests (left) and mean reminisced and forgotten items (right).

Converging evidence that reminiscence is a product of active searches comes from research concerning the role of elaborative encoding in hypermnesia. Mandler (1994) showed that hypermnesia is more likely when participants elaborate material at encoding. He classified studies that showed or did not show hypermnesia into presence or absence of elaborative encoding. The results revealed that of the 83 studies that showed hypermnesia, elaborative encoding was present in 71 (86%) of the studies whereas of the 46 studies that did not show hypermnesia, elaborative encoding was present in only 4 (9%) of the studies. Additionally, the results were essentially identical when Mandler excluded the studies that did not directly manipulate elaborative encoding, suggesting a clear relation between elaborative encoding and hypermnesia. Thus, it appears that elaborative encoding is a key component of reminiscence and hypermnesia.

How does elaborative encoding result in reminiscence and hypermnesia? There are two prominent theoretical accounts. The first is based on the Search of Associative Memory (SAM) model proposed by Raaijmakers and Shiffrin (1980, 1981); the second account is based on the relational / item-specific processing framework proposed by Hunt and McDaniel (1993). Consider first the SAM model. Two concepts in the SAM model can be used to explain hypermnesia: *incrementing* and *alternative retrieval routes* (see, e.g., Payne, Hembrooke, & Anastasi, 1993; Roediger & Challis, 1989). The former concept can be used to explain the fact that previously retrieved items are recalled faster on a repeated test than previously unrecalled items. The model assumes that recalling an item increments the associative strength between a stored image of the item and its retrieval cues, thereby making previously recalled items more accessible (relative to previously unrecalled items) on subsequent retrieval attempts. This view is relevant to the phenomena of reminiscence and hypermnesia because easier access to previously recalled items should decrease the likelihood that these items are lost on subsequent retrieval attempts, thereby minimizing intertest forgetting. Further, easier access to previously recalled items would provide additional time to search for new items.

Of course, additional time alone does not guarantee retrieval of new items. For new items to be retrieved, one must find alternative retrieval routes to the sought-after information, and this is where the second concept comes into play. This notion of alternative retrieval routes is based on the idea that a new set of cues is required to retrieve previously unrecalled items because using the same cues that failed before would only result in additional failures. Thus, elaboration is a key component of reminiscence and hypermnesia because elaborating an item at encoding increases the number of cues that would be potentially available for an item during retrieval. Obviously, inherent in this assumption is that participants actively search for alternative retrieval routes to uncover new items.

Now consider the second account: that hypermnesia is the product of item-specific and relational processing, but in different ways. As mentioned earlier, item-specific processing emphasizes item distinctiveness whereas relational processing emphasizes inter-connections between items. Hunt and McDaniel (1993) noted that some studies have shown greater improvement between test 1 and test 2 than between test 2 and test 3 whereas other studies have shown greater improvement between test 2 and test 3 than between test 1 and test 2. Hunt and McDaniel argued that existing theories cannot adequately explain these findings because they rely on a single process (e.g., cumulative recall levels) to explain hypermnesia. How can a single process produce improvement that sometimes occurs early in the retrieval process and at other times occurs later? Hunt and McDaniel proposed that these results reflect how relational and item-specific processing differentially affect reminiscence and intertest forgetting. That is, because relational processing minimizes intertest forgetting, improvement becomes visible early but declines as participants run out of items to recover. In contrast, item-specific processing facilitates reminiscence, but because this type of processing does not prevent intertest forgetting, improvement does not become visible until later when intertest forgetting reaches asymptote.

How does item-specific processing promote reminiscence? McDaniel, Moore, and Whiteman (1998) outlined two possibilities. First, unlike relational processing, item-specific processing does not promote a consistent retrieval plan across repeated tests. As a result, retrieval cues likely fluctuate across tests more when encoding is item-specific. One consequence of fluctuating cues is an increased likelihood of encountering new, and potentially more effective, retrieval cues that would facilitate reminiscence. However, cue fluctuation would also increase intertest forgetting because there would be a corresponding decrease in the likelihood of using previously successful retrieval cues. McDaniel et al.'s results were inconsistent with this hypothesis; they observed that reminiscence occurred toward the end of a recall period. This is contrary to the cue fluctuation hypothesis because if fluctuating cues are responsible for reminiscence, new items should be recovered throughout the recall periods, not just toward the end.

This pattern of results led McDaniel et al. (1998) to propose an alternative explanation. They argued that increased reminiscence is based on richer memory traces being created by item-specific processing relative to relational processing. They assumed that richer item traces would have a greater number of attributes, which would make retrieval cues more effective by increasing the likelihood that the cues match encoded attributes.

Unfortunately, McDaniel et al. did not explain how richer traces result in increased intertest forgetting while simultaneously increasing reminiscence. What is clear, however, is that McDaniel et al. also assume that reminiscence is a product of conscious searches.

In summary, there is converging evidence that reminiscence and hypermnesia are products of a conscious search of memory. As we have shown, the only way to obtain hypermnesia in a recognition paradigm appears to be to design the test in such a manner as to emphasize an active search. Further, we already knew that elaborative encoding plays an important role in producing hypermnesia in free recall. Finally, two prominent theories of hypermnesia assume that reminiscence requires conscious searches of memory. Despite all of this converging evidence there are data to support the view that reminiscence can occur in the absence of conscious searches, as outlined in the next section.

Reminiscence Does Not Require Conscious Searches

So far, the review of the literature would appear to indicate that conscious searches are necessary to recover previously unrecalled items. However, personal experience suggests that conscious searches may not be a necessary condition for reminiscence to occur. For example, the first author was on an airplane to Denver, Colorado for a conference. Sitting next to him was a couple doing a crossword puzzle. Obviously, they were experienced puzzle solvers. However, at one point, they were stuck, and what they did next caught the first author's attention. They closed their eyes and stayed still. Although the first author was afraid that they might be offended, he asked them what they were doing. The answer was, essentially, "nothing." They said that there was nothing going through their minds when they closed their eyes in search for the answer; they were simply waiting for the sought-after information to come to mind. They claimed that such a strategy had worked well in the past. Surely, the reader has encountered similar situations in which information that is being searched for is not readily available but "pops" into mind later when least expected. Experiences such as these suggest that one need not intentionally search for such information. That is, sought-after information can be retrieved from memory with little to no conscious effort.

A similar observation has been made by researchers in the tip-of-tongue (TOT) literature. The TOT occurs when a person fails to retrieve an answer to a posed question (e.g., "What is the capital of Australia?") but feels that recovery of the answer (Canberra) is imminent. Studies have shown that TOT states are resolved at a relatively high rate (see Schwartz, 2002).

For example, Burke, MacKay, Worthley, and Wade (1991) reported that the rate of resolving TOT states was 92% for young adults, 95% for middle-aged adults, and 97% for older adults. Of particular interest here is the method of resolving a TOT. There are several techniques available. These include looking up the answer, using strategies to search through memory, and waiting for the answer to "pop" into mind.

In the Burke et al. (1991) study, participants were asked to keep a diary of their TOT experiences for 28 days. The diary included answers to 11 questions regarding the type of word involved, the word that entered consciousness, and the type of strategy used to resolve the state. The results indicated that the most frequently reported method for resolving TOT states was to wait and let answers "pop" into mind. Interestingly, older participants were more likely to experience the "pop" into mind effect than middle-aged or younger adults. Further, there was a greater tendency for the middle-age group to use memory searches relative to either the young group or the older group. These results align with our intuition that the recovery of sought-after-information can occur without active memory searches, at least when individuals are experiencing a TOT state.

Does reminiscence occur in a similar way? We (Otani et al., 2002) sought to answer this question by examining whether participants actively search for previously unrecalled items. One approach that we adopted was to determine whether participants were aware of which previously unrecalled items might be recoverable on subsequent memory tests. We hypothesized that if participants actively searched for "new" items, then they should be aware of which items are recoverable, and, therefore, should focus their searches on these items. We tested this hypothesis by asking participants to indicate what they knew about unrecalled items.

Three experiments were conducted using different measures of knowledge. In the first experiment, we measured participants' knowledge by asking them to provide three types of information about unrecalled items: (1) the category to which the target belonged, (2) the first letter of the target, and (3) any other information that they had about the target. In the second experiment, we asked participants to indicate their feeling of knowing (FOK) about each unrecalled item. In the third experiment, we simply asked participants to predict which unrecalled items would be recovered on the second test. In all three experiments, participants were presented with a categorized list of 60 pairs of words and asked to process the list using either item-specific (pleasantness rating) or relational processing (category sorting). Participants then performed a two-minute filler task and completed two cued recall tests that lasted seven minutes each. On the first test, participants were asked to recall targets that had been studied with cues. If they failed to recall a target, they were asked to indicate their

Table 1. Number of Reminisced and Non-reminisced Items With and Without Knowledge.

	Reminisced		Non-Reminisced	
	With	Without	With	Without
		Experiment 1		
Relational	29	151	121	993
Item-specific	6	100	21	630
Both	35	251	142	1623
		Experiment 2		
Relational	57	31	489	601
Item-specific	48	52	370	553
Both	105	83	859	1154
		Experiment 3		
Relational	48	47	288	601
Item-specific	59	63	256	354
Both	107	110	544	955

knowledge of the missing target using the measures of knowledge just described. On the second test, participants completed another cued recall test, this time without indicating their knowledge of unrecalled targets.

Because the number of reminisced items that each participant produced was small, we had to collapse the data across participants. The reminisced items were then divided into those with versus those without participants' knowledge. As shown in Table 1, in all three experiments, the association between reminiscence and participants' knowledge was greater in the relational processing condition than in the item-specific processing condition (16% versus 6%, 65% versus 48%, and 52% versus 48%). The results of chi-square analyses confirmed that the association was significant in the relational processing condition [χ^2 (1) = 4.17 to 12.98, $p < .05$] but not in the item-specific processing condition [χ^2 (1) = 1.47 to 2.34, $p > .05$]. These results suggest that participants had some knowledge of recoverable items in the relational processing condition. However, in all three experiments, the number of reminisced items that were not associated with participants' knowledge was surprisingly large (88% in Experiment 1, 44% in Experiment 2, and 52% in Experiment 3). Apparently, participants had no idea whether many of the previously unrecalled items could be recovered. Of course, these results do not provide direct evidence that participants were not engaging in active searches. However, these results are at least consistent with the possibility that reminiscence may not necessarily require active memory searches. Perhaps, as illustrated by the couple on the airplane, the best strategy may indeed be to wait for a "new" item to pop into mind.

The results from another line of research also support the assertion that reminiscence is not necessarily the result of conscious retrieval processes. In these experiments, we (Widner, Otani, & Smith, 2000) compared hypermnesia in younger and older adults. We expected that older adults would exhibit less hypermnesia relative to young adults, in part, because older adults traditionally exhibit poorer memory performance than do young adults, especially on free recall tests. In the first experiment, we asked participants to study a list of 42 words. Following the presentation, participants performed a filler task for one minute and then completed three oral free recall tests each lasting five minutes. Further, half the participants completed these tests without any delay between successive tests whereas half completed the tests with a 15-minute delay between tests.

As shown in Figure 3, memory performance improved across the three tests for young adults whereas performance declined across tests for older adults. Thus, we failed to observe hypermnesia for older adults despite seeing it in younger adults in the same study. Why did the older adults not show hypermnesia? As shown in Figure 4, reminiscence was only slightly greater for young adults than for older adults (a non-significant effect). In contrast, intertest forgetting was much greater for older adults than young adults. Thus, older adults did not show hypermnesia because they lost more items across tests than they gained. However, the most notable finding was the failure to find a significant difference in reminiscence between young and older adults. This finding led us to entertain the notion that reminiscence and recall are based on different processes, and that reminiscence may be a function of automatic processing. That is, recall is based on effortful processing that declines with age whereas reminiscence is based on automatic processing that does not decline with age. As noted by Hasher and Zacks (1979), a failure to find age differences is one indication that the underlying process(es) may be more automatic than controlled.

In the second experiment, we used pictures rather than words, again because past studies that failed to show hypermnesia often used words as study material (see Payne, 1987). Also, we asked half of the participants to perform a distractor task between tests because the difference between young and older adults could potentially be accounted for by the young adults' tendency to rehearse study material between tests. Further, because improvement was greater when there was a delay between tests, we inserted a 15-minute delay between tests for all participants.

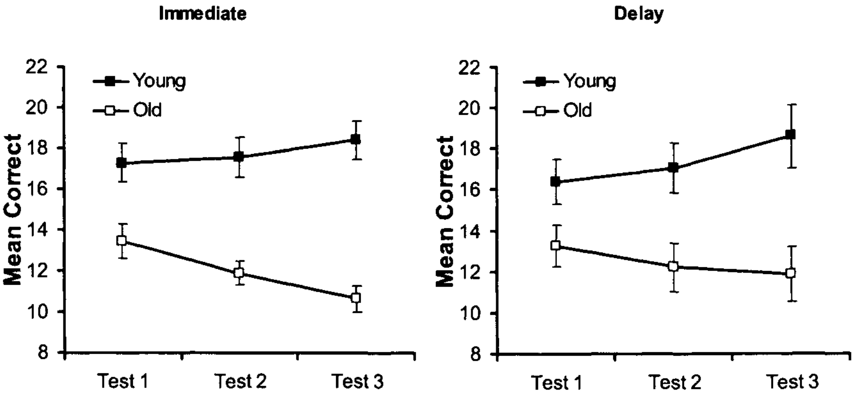

Fig. 3. Mean correct items as a function of age and test for the immediate (left) and delay (right) conditions.

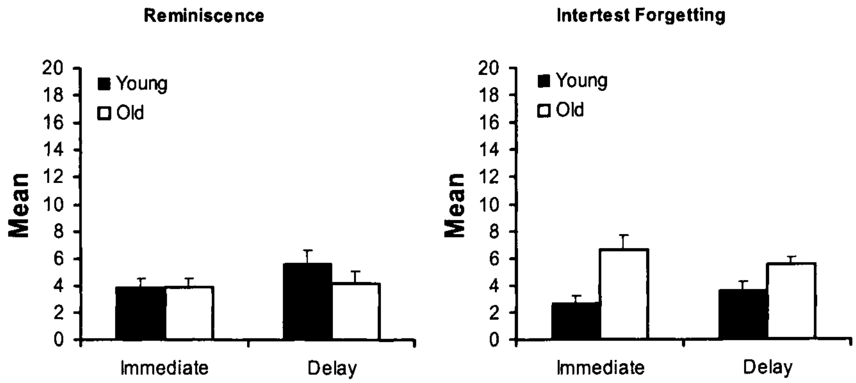

Fig. 4. Mean reminisced (left) and forgotten (right) items as a function of age and condition.

The results, shown in Figure 5, were similar to those in the first experiment. Once more, hypermnesia only occurred for younger adults. Also, reminiscence was similar between younger and older adults whereas intertest forgetting was greater for older adults than for younger adults (Figure 6). Contrary to our expectation, filling the intervals between tests did not impact the outcome. These results, therefore, support the assertion that reminiscence and recall are dissociable. Does this mean that reminiscence is based on automatic processing whereas recall is based on effortful processing? The answer to this question may not be as straightforward as it might appear. However, these results, together with the results showing that reminiscence does not require participants' knowledge of unrecalled items, are consistent with the notion that reminiscence may be based on automatic processing. We, therefore, conducted another set of experiments to examine this hypothesis in greater detail.

In these experiments, we (Otani et al., 2003) compared reminiscence in explicit and implicit memory. In the literature, explicit memory is often assessed using direct tests (e.g., free recall) whereas implicit memory is assessed using indirect tests (e.g., word stem completion). The difference between these two types of tests is that in the former participants are asked to retrieve study items whereas in the latter participants are simply asked to perform the task without any mention of the study material. Thus, using implicit memory tests, it would be possible to test the hypothesis that reminiscence does not require active searches of memory. What type of implicit memory might reminiscence represent? Generally, implicit memory tests are classified into conceptually-driven and data-driven tests. The distinction between these two categories is based on whether performance is influenced by conceptual manipulations (e.g., level of processing at encoding) or perceptual manipulations (e.g., modality of presentation at encoding and retrieval; Toth, 2000). Because elaborative encoding appears to be a key component of reminiscence and hypermnesia, we reasoned that reminiscence is likely based on conceptually-driven implicit memory processes. Such a view would account for the failure to find age differences in reminiscence because, as Maki, Zonderman, and Weingartner (1999) reported, conceptually-driven implicit memory reveals relatively small age effects.

In the first experiment, we presented two groups of participants with a categorized list of 72 words. In an effort to maximize the likelihood of observing reminiscence, we asked participants to rate the pleasantness of each word. Next, participants performed a filler task for five minutes followed by three tests that lasted seven minutes each. The tests were either category cued recall tests (explicit) or category generation tests (implicit). On the category cued recall tests, participants were presented with the

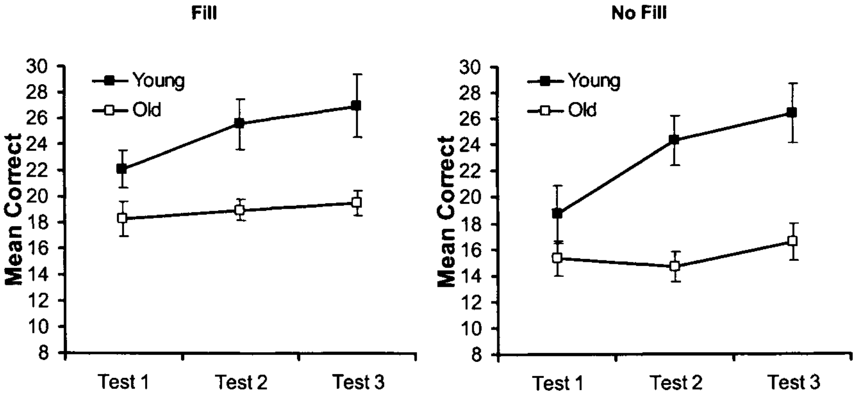

Fig. 5. Mean correct items as a function of age and test for the fill (left) and no fill conditions (right).

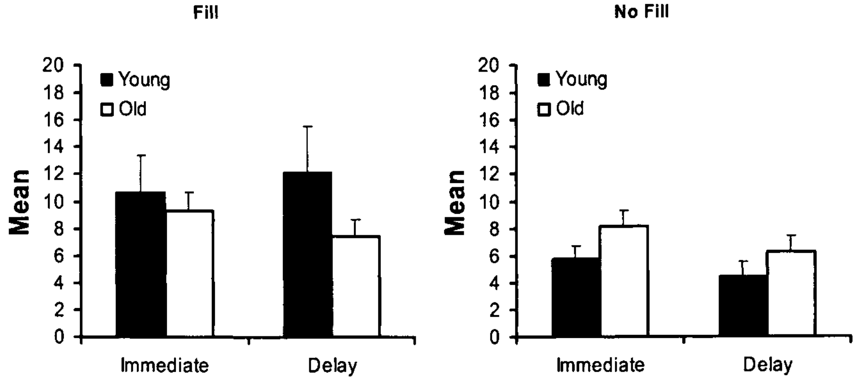

Fig. 6. Mean reminisced (left) and forgotten (right) items as a function of age and condition.

category labels and asked to recall the study words that belonged to each category. On the category generation tests, participants were also presented with the category labels; however, they were asked to generate as many instances of each category as possible. There was also a control condition in which participants were asked to perform the category generation tests without being exposed to the study list. This condition was included to assess baseline performance on category generation.

First, we examined the number of reported items that were on the study list (i.e., *old* items). As shown in Figure 7, there was an increase in performance across the three tests for participants in the explicit memory condition. In contrast, we failed to observe any improvement for participants in the implicit memory and control conditions, even though participants in the implicit memory condition produced more old items than did participants in the control condition – that is, those in the implicit memory test condition displayed priming. Interestingly, the priming effect disappeared on the second and third tests. Additionally, we examined these data by excluding "aware" participants (those who indicated that they knew that the category generation tests were used to assess their memory of study items). Despite this change in the analysis we did not observe a change in the results.

Next, we examined reminiscence. As can be seen in Figure 8, we observed an interaction between memory group and test. On the second test, we observed a greater amount of reminiscence for the explicit and implicit memory groups relative to the control group, with no difference between the explicit and implicit test groups. On the third test, there was no difference among the three groups. These results are consistent with the hypothesis that reminiscence should be the same regardless of whether participants actively search for unrecalled items (explicit memory) or did not actively search for unrecalled items (implicit memory). However, when the "aware" participants were excluded, the results were less conclusive. On the second test, the difference between the explicit memory and control groups was still significant. However, the implicit memory group was no longer significantly different from either group.

Because the results were not clear cut, we decided to switch to a study list that was loosely categorized. Our goals were to reduce the number of "aware" participants and to lower guessing rates. Our assumption was that by making the categorical nature of the study list less obvious, participants would be less likely to be aware of the relation between the study list and the category generating test. Further, we assumed that the guessing rate should be lower if categories were less well defined. We constructed a

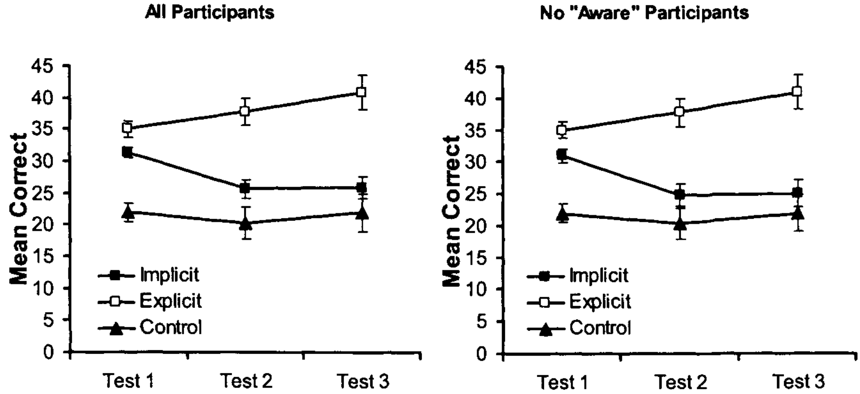

Fig. 7. Mean old words as function of condition and test for all participants (left) and after excluding the "aware" participants (right).

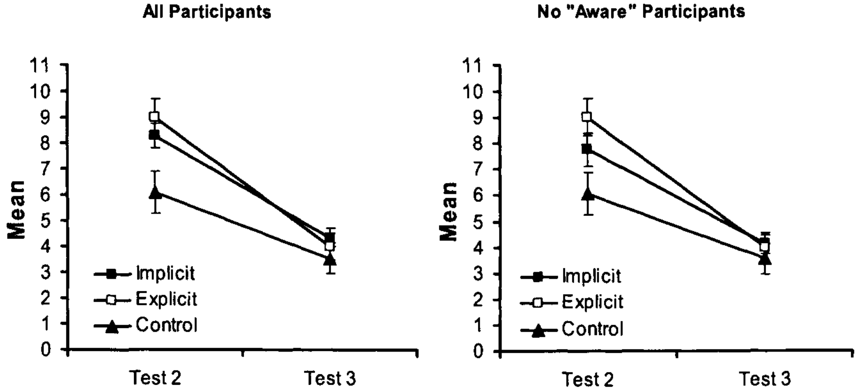

Fig. 8. Mean reminisced old words as a function of condition and test for all participants (left) and after excluding the "aware" participants (right).

study list by selecting 12 words from each of six ill-defined categories (e.g., soft). All other aspects of the procedure were the same as in the prior experiment.

As shown in Figure 9, performance improved across the three tests for participants in the explicit memory condition; however, performance remained relatively constant across tests for participants in both the implicit memory and control conditions. Further, the differences between the implicit memory and control conditions were significant on the first and third tests but not on the second test. Removing "aware" participants did not alter these patterns. Next, we analyzed reminiscence. As shown in Figure 10, reminiscence differed among the three memory conditions. Contrary to what we expected, we observed the greatest amount of reminiscence in the explicit memory condition, followed by the implicit memory and control conditions, respectively. The difference was significant for all three conditions, and the pattern was the same for both the second and third tests. These results were unaltered when we excluded "aware" participants.

The results of the two experiments provide some insight into the role of active retrieval in producing reminiscence. As shown, even when participants were not actively searching for study items, they could recover new items on a repeated test. Thus, it appears that reminiscence does not necessarily require active searches of memory. However, we did observe that the amount of recovery was greater when participants had engaged in active searches. These results, therefore, indicate that we can find more items when we actively look for them relative to when we simply wait for them to come to us. Thus, there appears to be two types of reminiscence: one that occurs as a result of active searches (voluntary) and one that occurs without active searches (involuntary), with the former being more prevalent than the latter.

How does involuntary reminiscence work? It is possible that a failed attempt to retrieve a target on the first retrieval attempt primes the target by activating temporarily inaccessible memory traces, an idea proposed by Yaniv and Meyer (1987). In their experiment, participants were asked to produce a rare word when provided with its definition. If they failed to come up with the word, they then were asked to make a judgment as to whether they were experiencing a TOT state and to rate the strength of their FOK. Following these judgments, participants were asked to complete a series of lexical decisions that included the target word. The results indicated that when participants had a TOT experience with a strong FOK, they showed faster lexical decision times toward target words relative to control words, even though the target words were not retrieved during the initial phase.

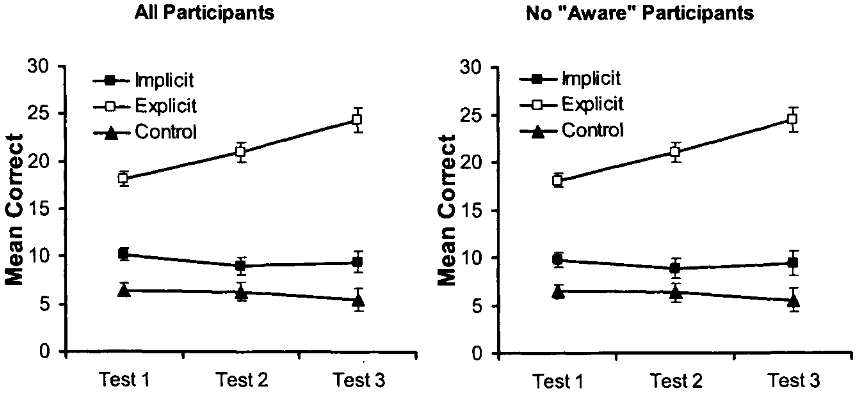

Fig. 9. Mean old words as function of condition and test for all participants (left) and after excluding the "aware" participants (right).

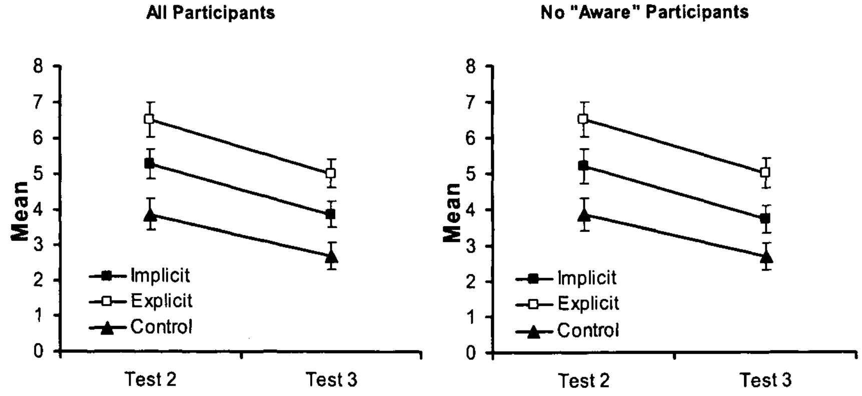

Fig. 10. Mean reminisced old words as a function of condition and test for all participants (left) and after excluding the "aware" participants (right).

The explanation offered by Yaniv and Meyer (1987) for this pattern was that the initial failure to retrieve the targets may have sensitized participants to the sought-after information by partially activating the temporarily inaccessible target words. It is possible that involuntary reminiscence occurs when this activation level reaches a certain threshold. However, Yaniv and Meyer found the priming effect only when participants had strong FOK experiences. In contrast, our results revealed that reminiscence occurred even when participants did not have a FOK experience. Alternatively, one might argue that involuntary reminiscence may be based on the way that participants sample cues on a repeated test. It is assumed that when participants output all of the recallable items on a repeated test, they then begin sampling cues to retrieve additional items. These cues could be target items that they have already recalled or contextual cues that they generated based on the type of study list (e.g., a categorized list). It seems reasonable to assume that these cues could activate target words that were too weak to be activated on the first test. Once such items are exhausted, individuals would have to actively search for additional items using whatever strategies they had available. Our assumption is that elaborative encoding of the target items, such as would be fostered by item-specific processing, becomes important when participants actively search for new items.

Conclusion

The literature on hypermnesia indicates that reminiscence requires active searches of memory. However, as we have pointed out in this chapter, such a notion is inconsistent with our subjective experience of unrecalled items sometimes "popping" into mind. Our initial investigation revealed that reminiscence occurs even when participants have no knowledge of previously unrecalled items (i.e., to-be-reminisced items). We inferred from this finding that participants are not actively targeting items for recovery and, therefore, that reminiscence does not require active searches. Further, the observed reminiscence is similar between younger and older adults, which led to us to hypothesize that reminiscence is based on automatic processing because a failure to find age differences is sometimes indicative of automatic processing. Finally, we compared explicit and implicit memory performance and showed that reminiscence occurs even when participants are not instructed to engage in an active retrieval process. However, our results also indicated that the amount of reminiscence is greater when participants are instructed to actively search for to-be-reminisced items (i.e., an explicit memory instruction) than when they are not (i.e., an implicit memory instruction).

Based on these data, we proposed that there are two types of reminiscence, one voluntary and the other involuntary. It would appear that although the voluntary kind may be more probable, the likelihood of the involuntary kind is certainly greater than zero. At present we cannot specify the mechanism(s) that underlie involuntary reminiscence; however, the existence of such reminiscence is in line with our experience that recovery sometimes occurs without active memory searches.

Lastly, what are the implications of the existence of the two types of reminiscence to the dynamic processes of memory retrieval? One implication is that, as we mentioned at the beginning of this chapter, single trial testing does not capture the essence of dynamic memorial processes that occur in real world settings. As shown by our research and others, memory performance does not remain the same when retrieval attempts are repeated. The second implication is that memory retrieval is a dynamic interplay of explicit and implicit processes. One of our future research goals is to determine exactly how these processes interact when retrieval attempts are repeated. We hope that by doing this, we will be able to identify procedures for more efficiently recovering previously unretrieved information.

Author Notes

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Age-Related Changes in Event-Cued Prospective Memory Proper

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Summary. Prospective memory proper (ProMP) is required to bring back to awareness previously formed plans and intentions at the right place and time, and to enable us to act upon those plans and intentions. This chapter defines ProMP and distinguishes it from other subdomains of prospective memory (ProM) such as vigilance/monitoring, reviews previous research on and presents the results of a quantitative meta-analysis of age-related changes in event-cued ProM, and reports on a new study examining the relations between ProMP, retrospective memory (RetM), processing resources, and sensory abilities (visual and auditory acuity). The review of previous research indicates that both ProMP and vigilance show substantial declines with aging, that age-declines in ProMP are larger than in vigilance/monitoring, and these age declines have been underestimated in a large portion of the previous studies due to methodological shortcomings such as ceiling-limited scores (ceiling effects) and age confounds in research design. The new study reveals age-related declines in both visual and auditory ProMP that are partially mediated by declines in processing resources and sensory abilities. The combined results highlight the importance of processing resources and sensory functions in mediating age declines in ProMP and delineate the similarities and differences between RetM and ProMP.

Key words. Memory, prospective memory, aging, sensory functions

Introduction

To bring back to awareness previously formed plans and intentions at the right place and time, we rely upon prospective memory (ProM). A typical situation requiring prospective memory is to buy groceries en route home from work, as modeled and illustrated in Figure 1. First, we make a plan to get the groceries; second, we go about our daily activities and perform

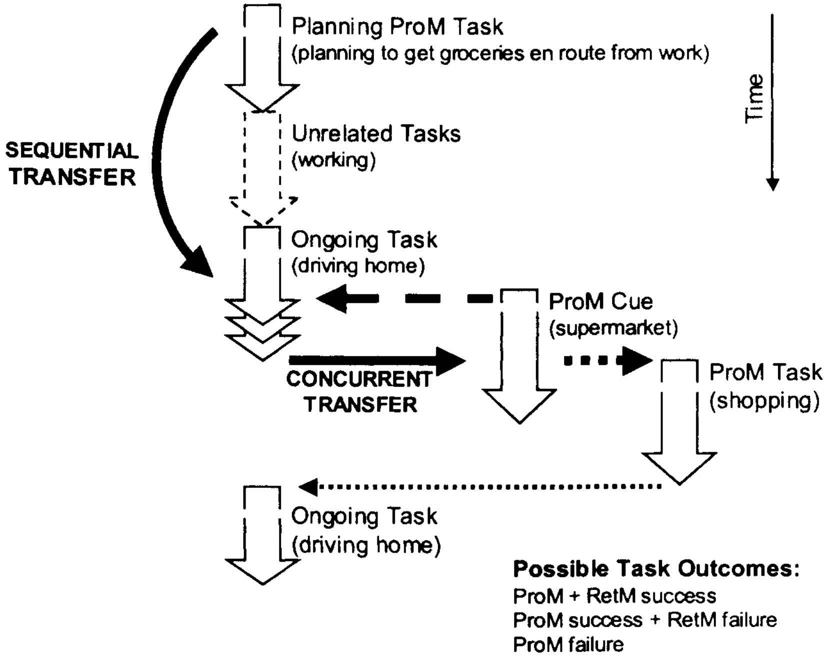

Fig. 1. A task analysis of a typical ProMP situation: A plan to buy groceries en route from home.

various tasks unrelated to our plan; third, we commence the ongoing task of driving home. While driving home, the ProM cue, the supermarket, appears, and the critical question is whether the cue interrupts the ongoing activity and we become aware of its relevance to the previously formed plan. If so, we have succeeded on the defining component of prospective memory function: becoming aware of the plan. The success in performing the ProM task now depends on retrospective memory, the ability to recollect what groceries to buy. Accordingly, when we arrive home, we may arrive without the groceries due to either a ProM failure or a retrospective memory (RetM) failure (i.e., which groceries to buy). Alternatively, if both ProM and RetM functions succeed, we arrive home with all of the groceries (or at least those that the supermarket had in stock!).

The main goal of this chapter is to examine age-related changes in event-cued ProM. Toward this end, the chapter is divided into three sections. The first section defines ProM Proper (ProMP; Graf & Uttl, 2001), distinguishes it from RetM as well as from other subdomains of ProM such as vigilance and monitoring, highlights the dynamic interplay between the ongoing task and the ProM cue, and outlines issues in the assessment of

ProM Proper. The second section reviews previous research on ProM and aging from both conceptual and methodological perspectives, and presents a meta-analysis of age-related changes in ProM Proper as well as in vigilance/monitoring. The third section presents new research that investigates both age-related changes in visual and auditory ProM Proper, and whether age declines in visual and auditory ProM are mediated by declines in processing resources and sensory functions such as visual and auditory acuity.

Prospective Memory Proper (ProMP)

Prospective Memory vs Prospective Memory Tasks

As demonstrated by the example given earlier, ProM tasks have two components: prospective and retrospective (Dobbs & Rule, 1987). Although it is widely recognized that only the prospective component involves prospective memory and that the retrospective component is no different from recollecting a list of words (e.g., groceries to buy) upon demand, the majority of previous studies have confounded the two components into a single binary measure of prospective memory task success or failure. However, as shown in Figure 1, making inferences about the prospective component based on task success or failure data alone is not optimal and may even be wrong.

Following Dobbs and Rule (1987), we have argued that the prospective component can be measured more directly (Graf & Uttl, 2001; Uttl, Graf, Miller, & Tuokko, 2001). Participants in our study (Uttl et al., 2001) – 133 community-dwelling older adults from 65 to 95 years of age – were required to perform a variety of cognitive tasks. For one of the ProM tasks, participants were told that, in the course of the experiment, when I [the experimenter] say "this is the end of the task, I would like you to ask for a pen and a piece of paper, and then I would like you to write your name on the paper." Participants then performed various tasks and at the end of one the experimenter said, "this is the end of the task." Participants indicated that they recognized this cue as a sign to perform the ProM task by responding to it with comments such as "we need to stop here for another task" or "oh, there is something I have to do now," by explaining that they have to do something, or by asking for the pen and/or the paper. These responses to the cue indexed the ProM component success and were independent of the RetM component. Our results showed similar age-related declines in both ProMP and RetM and revealed only a weak relationship between the indexes of ProMP and RetM.

Subdomains of Prospective Memory

A quick survey of the research that has been conducted under the umbrella of prospective memory reveals that the "prototypical" ProM task encompasses such diverse behaviors as preventing a kettle from boiling over, monitoring air traffic on a radar screen, buying groceries en route home, booking an airline ticket, taking medication at prescribed times, and paying bills.

Although all of these situations involve making a plan and performing the plan sometime in the future, the tasks differ in important ways. For some tasks, a plan is maintained in consciousness throughout the retention interval (e.g., scanning for airplanes) whereas for other tasks, the plan leaves consciousness. The critical question is whether the ProM cue brings the plan back to consciousness (Kvavilashvili, 1998; Mantyla, 1996; Graf & Uttl, 2001). We (Graf & Uttl, 2001) have argued that this difference in conscious experiences associated with different prospective memory tasks is analogous to the experiences that characterize primary and secondary memory (James, 1890). By analogy to William James (1890), we have proposed that prospective memory proper requires that "we are aware of a plan, of which meanwhile we have not been thinking, with the additional consciousness that we had made the plan earlier" (Graf & Uttl, 2001, p. 444). This definition distinguishes ProM Proper from vigilance and monitoring, that is, from prospective memory tasks that dominate working memory and conscious awareness during the retention interval.

Moreover, some tasks, such as taking medication at bedtime, are referred to as habitual ProM tasks (Harris, 1984; Meacham, 1982) and involve the execution of the same plan in response to the same cue many times over; other tasks, such as buying groceries, are referred to as episodic ProM tasks and require the execution of the plan only once. This distinction between habitual and episodic ProM tasks is analogous to the distinction between semantic and episodic memory tasks (Graf & Uttl, 2001).

Table 1 highlights the correspondence between the subdomains of retrospective and prospective memory. Although these distinctions have been recognized in the literature, they are frequently ignored. Only a careful reading and analysis of the method section of an article reveals whether a particular study is concerned with ProM Proper rather than with vigilance/monitoring or habitual ProM.

Table 1. The subdomains of retrospective and prospective memory.

Retrospective memory	Prospective memory
Short-term/Working Memory	**Vigilance/Monitoring**
Looking up and dialing phone number	Preventing a kettle from boiling over
Long Term Memory	**ProM Proper**
Encoding and recollecting past events	Buying groceries en route home
Semantic Memory	**Habitual ProM**
Knowing facts, things, and procedures	Taking medication every day

ProM vs Retrospective Memory

One of the distinguishing features of ProM, as opposed to RetM, is the recognizing of cues as signs of previously formed plans when the cues appear as part of ongoing thoughts, actions, or situations (Craik, 1983, 1986; Graf & Uttl, 2001). To illustrate, when driving by the supermarket, no one alerts us to pay attention to this cue and no one instructs us that we should stop there and get the groceries. These similarities and differences are highlighted in Table 2 (adapted from Graf & Uttl, 2001). As illustrated, the critical difference between ProM and RetM tasks is that for all RetM tasks participants are alerted to the cues and instructed to work with them in a task-relevant manner. In contrast, for ProM tasks, participants are not alerted to the presence of the cues nor are they reminded to work with them in the manner relevant to the previously conceived plan.

In applying the idea of transfer appropriate processing (TAP; Morris, Bransford, & Franks, 1977) to the ProM domain, Meier and Graf (2001) highlighted another difference between ProM and RetM. For RetM tasks, TAP predicts that RetM test performance depends on the degree of processing overlap between study and test. In contrast, the ProM tasks allow for two kinds of processing transfers: a sequential transfer dependent on the overlap between planning stage processing and ongoing task process-

Table 2. Properties of Explicit, Implicit, and Prospective Memory test

Type of memory test	Cues provided at test	Participants alerted to cues at test	Participants alerted to relevance of cues
Explicit	Yes	Yes	Yes
Implicit	Yes	Yes	No
Prospective	Yes	No	No

ing, and a concurrent transfer dependent on the overlap between ongoing ongoing task processing and ProM cue processing (see Figure 1; see also Maylor, 1996; Darby & Maylor, 1998). Early studies support TAP both for sequential transfer (McDaniel, Robinson-Riegler, & Einstein, 1998) and for concurrent transfer (Meier & Graf, 2001); they suggest that the TAP principle also applies within the domain of ProM.

Dynamic Interplay Between ProM Cue and Ongoing Task

As stated earlier, ProM Proper depends critically on whether the cue interrupts the ongoing activity and whether we become aware of its relevance to the previously formed plan. However, whether the ProM cue manages to interrupt the ongoing activity is dependent upon the nature and momentum of the ongoing activity. Thus, ProM depends on the dynamic interplay between the ongoing task demands and the ProM cue properties.

Research has already identified several properties of ProM cues that make them more intrusive, more likely to be noticed, and more likely to interrupt the ongoing task. These factors include the appearance of the ProM cue on center vs off center of ongoing task focus (Uttl & Ohta, 2004), ProM cue size (Graf, Uttl, & Dixon, 2002; Uttl & Graf, 2000a), ProM cue distinctiveness (Brandimonte & Passolunghi, 1994; Einstein, McDaniel, Manzi, Cochran, & Baker, 2000; Graf et al., 2002; Uttl & Graf, 1999), and ProM cue novelty (Brandimonte & Passolunghi, 1994; Einstein & McDaniel, 1990; McDaniel & Einstein, 1993).

On the other side of this dynamic equation are the properties and demands of the ongoing task. First, ongoing tasks vary in the degree to which they demand resources and, consequently, they leave more or fewer resources for processing of ProM cues. Moreover, participants may decide to allocate more or fewer resources to the ongoing task. To illustrate, Uttl and Graf (2000a) required 111 older participants to perform a resource-demanding A/B card sorting task (i.e., ongoing task) on three consecutive blocks of trials. Participants performed the ongoing task alone on the first block. On the second block, they performed the ongoing task while various photos of common objects appeared on the computer screen at the same time as each to-be-sorted card. The third critical block of trials was the same as the second block except that the ProM cue appeared embedded among the photos of objects. Uttl and Graf found that ProM performance—stopping the ongoing task when the ProM cue was noticed and recognized as relevant to the previously formed plan—was strongly related ($r = -.74$) to the difference between speed of A/B card sorting on the third vs the first block of trials. Participants who allocated more resources to the ongoing task performed more poorly on the ProM task and vice versa. Other researchers have reported similar negative effects of the ongoing task demands on ProM performance using a variety of tasks located closer to the vigilance/monitoring end of the prospective memory task continuum (e.g., Marsh, Hancock, & Hicks, 2002; Kidder, Park, Hertzog, & Morrell, 1997; West & Craik, 1999).

Second, ongoing tasks also vary in the flow of ongoing activities, making some tasks easier to interrupt than other tasks. Graf (2004, also see this volume) distinguishes between high vs low ongoing task momentum. High momentum tasks are smooth and rapid-flowing with minimal unfilled pauses whereas low momentum tasks are slow-moving and include many unfilled pauses. To illustrate, in the study by Uttl and Graf (2000a) discussed earlier, each decision immediately triggered the appearance of the next card and the start of the next trial. Thus, the flow of the ongoing activities was rapid and a strong negative correlation was observed between the degree of resource allocation to the ongoing task and ProM Proper. In contrast, Uttl & Graf (2002) used the same A/B card sorting task but participants had to wait and watch for the start of the next trial that appeared several hundred milliseconds later. The insertion of these inter-trial pauses slowed down the flow of the ongoing task and lowered the correlation between the index of resource allocation to the ongoing task and ProM performance.

Assessment of ProM Proper

Despite a growing interest in ProM, progress has been impeded by a lack of valid, reliable, and efficient measures of ProM. As already noted, most of the previous investigations have measured ProM by recording either success or failure on ProM tasks, thereby confounding ProM and RetM components in a single index of performance. Moreover, the vast majority of prior investigations has indexed ProM performance either by a single success/failure trial or by an average of multiple success/failure trials. The principal limitation of single success/failure indexes as measures of any ability is that they are inefficient; they provide only a very coarse measurement of underlying abilities, and they frequently are limited by ceiling and floor effects. Unfortunately, the averaging of success/failure data across multiple trials to obtain a more finely-graded index of ProM performance is also problematic because repeated responding to ProM cues ensures that the ProM plan remains in participants' consciousness and such a summary indexes no longer reflects ProM Proper but rather vigilance/monitoring. Thus, a critical challenge in the assessment of ProM

Proper is to develop and validate multiple measures that gauge ProM independently of RetM (see above) and yield continuous indexes of performance.

We have recently developed a continuous index of Visual ProM Proper based on a simple idea. Our approach employs ProM cues (pictures) whose intrusiveness (i.e., size) increases over time to the point of being almost impossible not to notice. The dependent variable is the cue size when participants respond to it. Specifically, participants are shown a ProM cue – a picture of a helicopter or a teddy bear – and they are told to stop whatever they are doing when they notice the ProM cue anytime and anywhere in the experiment. In the experiment, participants are engaged in an attention-demanding ongoing task, the A/B card-sorting task described earlier. While sorting the cards, pictures of common objects appear in various sizes in the four corners of the screen and the pictures are replaced by different pictures with each key press. The size of each picture is determined randomly from trial to trial within the specified range. At some random point, the ProM cue appears among these pictures. If a participant fails to notice the ProM cue, it appears again a few trials later, but this time in a larger size. The cue grows larger across trials until the participant responds to it or until the maximum size is reached. In a series of experiments, we have demonstrated that this method provides a valid and reliable index of ProM Proper in both young and older adults (Uttl & Graf, 1999, 2000a, 2000b, 2000c, 2002; Graf, Uttl, & Dixon, 2002).

Section Summary

ProM is divided into subdomains of ProMP, vigilance, and habitual ProM. Failure to acknowledge the differences between ProMP, vigilance, and habitual ProM hinders the interpretation of previous research findings, leads to contradictory findings, and likely impedes progress in ProM research. Moreover, although it has long been recognized that performance on ProM tasks reflects both prospective and retrospective components, one of the current challenges in measurement of ProM is to measure the prospective component uniquely, eliminating or at least reducing the RetM load on ProM task performance. Another challenge is to replace inefficient binary success/failure indexes of ProM with reliable and valid continuous indexes of ProM.

Age-related Differences in Prospective Memory Proper

Theoretical Expectations

In his influential account, Craik (1983) proposed that all memory tasks can be arranged on a continuum according to the degree to which they provide environmental support (e.g., cues). Moreover, tasks providing little or no environmental support require the greatest amount of subject-initiated processing. By this view, augmented by the assumption that aging results in a reduction of processing resources, memory tasks providing little or no environmental support would be expected to show the largest age-related declines. Craik's view predicts that, in general, ProM Proper will show larger age-related deficits than will explicit episodic RetM because by their very nature ProM tasks provide little or no environmental support. Overall, the wealth of accumulated research on RetM supports Craik's theoretical account, but thus far there has been insufficient research to clarify whether ProM Proper is consistent with it. Previous research has revealed age-related declines in ProM Proper in adults 65 years and older (Uttl & Graf, 1999; Graf et al., 2002) but it is not yet clear whether such declines are larger than in RetM.

In related theoretical accounts, Pichora-Fuller, Schneider, and Daneman (1995) and Schneider and Pichora-Fuller (2000) have argued that age-related declines in performance on a variety of cognitive tasks may be the result of impoverished stimulus representations due to age-related declines in sensory functions (Anstey, Stankov, & Lord, 1993; Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994; Salthouse, Hancock, Meinz, & Hambrick, 1996). By this view, declines in sensory functions (e.g., visual acuity, auditory acuity) lead to impoverished or inaccurate representations of stimuli, and in turn, the impoverished representations demand more top-down processing, deplete limited processing resources, and in turn lead to degradation in other resource-demanding cognitive processing. Cast in Craik's (1983) framework, age declines in sensory functioning result in less environmental support for older adults and demand more self-initiated processing. Given the age declines in sensory functioning and the necessity for the ProM cue to be noticed and to interrupt the ongoing activity, we may expect large age declines on ProM tasks and a strong relation between sensory functioning and ProM task performance.

It is also possible, however, that declines in both cognitive and sensory functioning are caused by a third factor, such as widespread neural degeneration, decrements in the vascular system, or a loss of temporal synchrony (Lindenberger & Baltes, 1994; Salthouse et al., 1996). According to this perspective, for example, age-related changes in neuronal matter serving both peripheral and central processing cause declines both in sensory abilities such as visual and auditory acuity and in cognitive abilities such as memory and reasoning. Regardless of which theoretical view ultimately prevails, all accounts predict age declines in performance on ProM tasks, and all emphasize the relation between sensory functioning and ProM performance.

Review of Prior Research and Methods

The starting point for the majority of research on age-related changes in prospective memory has been Craik's (1983) prediction that age effects would be particularly large on prospective vs other memory tasks. Surprisingly, in one of the early attempts to examine Craik's prediction, Einstein and McDaniel (1990) found no age-related deficits in prospective memory and proposed that "prospective memory seems to be an exciting exception to typically found age-related decrements in memory" (p. 724). In the flurry of studies that have followed their unexpected discovery, Einstein, McDaniel, their colleagues and others who adopted Einstein and McDaniel's prospective memory task (Cherry & LeCompte, 1999; Cherry et al., 2001; Einstein et al., 1995; Kliegel, McDaniel, & Einstein, 2000; McDaniel, Einstein, Stout, & Morgan, 2003) continue to find no age-related declines in prospective memory. Yet other researchers continue to find substantial age-related declines on ProM Proper as well as on other prospective memory tasks (e.g., Uttl & Graf, 1999; Graf et al., 2002; Huppert, Johnson, & Nickson, 2000; Park, Hertzog, Kidder, Morrell, & Mayhorn, 1997; Rendell & Craik, 2000; Uttl et al., 2001). What could account for these discrepant findings and contradictory claims?

Age effects are limited by ceiling effects

Figure 2 reviews the size of age effects found in various experimental conditions in studies that have investigated age-related differences in event-cued prospective memory. This figure shows the magnitude of age declines (i.e., young minus older adults' performance) as a function of older adults' performance. The figure highlights that (a) older adults performed more poorly than younger adults in the vast majority of conditions, and (b) older adults' performance strongly predicts, in linear fashion, the size of age-related declines: The closer the older adults are to the ceiling, the smaller are the age-related declines. In the extreme, when older adults reach maximum scores, age declines are predicted to be zero. This is not because of the lack of age-related decline in any ability, however, but

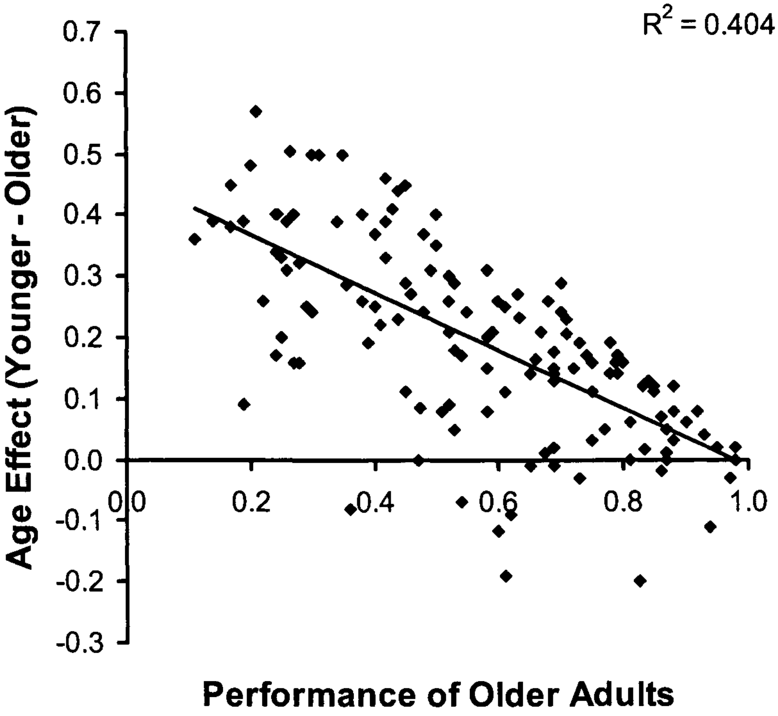

Fig. 2. The size of age declines (i.e., performance of younger minus performance of older adults) in prospective memory as a function of older adults' performance. Each data point is based on mean performance of younger and older adults expressed as proportion correct in one experimental condition. The figure is based on data from 40 published studies with 133 experimental conditions.

rather because of ceiling effects in performance due to ProM tasks that are too easy.

Figure 2 highlights that ceiling effects in measurement likely reduce age-related differences in the majority of studies that have investigated age-related changes in ProM and are responsible for at least some of the null findings. Although some researchers acknowledge that their ceiling-limited data should not be used to make inferences about the lack or size of age-related differences in performance (e.g., Maylor, Smith, Della Sala, & Logie, 2002; Uttl et al., 2001), others have nevertheless interpreted them as indicating that age does not impact the abilities necessary for performance on prospective memory tasks. Such interpretation of ceiling-afflicted data is unwarranted.

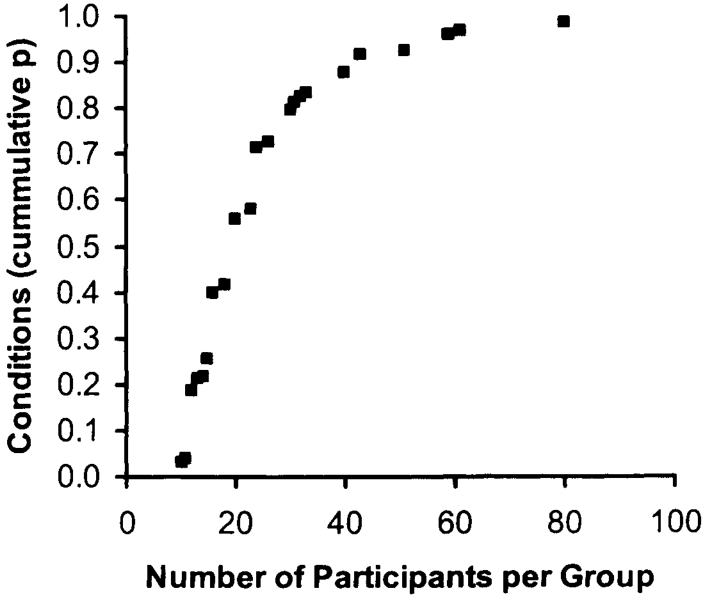

Fig. 3. The cumulative proportion of experimental conditions as a function of number of participants in each age group.

Low statistical power ensures null age effects

The review of previous research indicates that many studies have used such small numbers of participants in various experimental conditions that the chance of finding even a large age effect (0.8 SD) has been smaller than that of flipping heads on a fair coin. If we assume that age declines in ProM are as large as 0.8 SD, we need at least 26 participants per age group to find such a large effect statistically significant 80 times out of 100 (Cohen, 1988, 1992a, 1992b). However, the review reveals that experimental conditions rarely have included more than 26 participants per age group.

Figure 3 shows a cumulative proportion of experimental conditions as a function of the number of participants in each age group and in each experimental condition. This figure shows that more than 70% of all comparisons in prior research were based on fewer than 26 participants in each of the two age groups, and that a substantial proportion of studies (40%) used 16 or fewer participants per group. Thus, the null effects of age observed in some of the smaller-sized studies may be due to low statistical power. Any claims that aging does not affect performance on prospective memory tasks based on such small sample sizes are not warranted by existing data.

Binary success/failure measures are inefficient and imprecise

To measure an individual's performance on prospective memory tasks, almost all previous investigations of ProM have used either a single success/failure trial (with a success scored as 1 and a failure scored as 0) or an average across multiple success/failure trials. As discussed earlier, the principal limitation of a single success/failure index as a measure of any ability is that it provides only a very coarse measurement of any underlying ability and is unable to measure fine individual differences in relevant abilities.

In the absence of continuous measures of prospective memory, many investigators have chosen to present participants with a ProM cue repeatedly and to average success/failure data over repeated ProM cue presentations. To illustrate, Einstein and McDaniel (1990) presented each participant with three ProM cues and averaged the three success/failure observations to obtain less coarse performance estimates for each participant. However, even this measurement gradation, combined with only 12 participants in each condition, results in large jumps in condition means caused entirely by a single participant's performance: one participant's poor performance could lower the mean proportion in an experimental condition by as much as 0.08.

To obtain a finer gradation in measurement, other investigators have presented examinees with as many as 20, 30, or even more ProM cues (e.g., Martin, Kliegel, & McDaniel, 2003; McDermott & Knight, 2004; Rendell & Craik, 2000; Vogels, Dekker, Brouwer, & de Jong, 2002). To illustrate, Rendell and Craik (2000) engaged participants in a board game called "virtual week." During the course of the game, participants moved a token around the board according to the number shown on a simulated die. Each circuit of the board represented one day and was completed by participants in 5 to 10 minutes. Each "day," participants were to perform ten ProM tasks including four irregular (event-based) tasks. Accordingly, on average, participants were to perform one ProM task every 30 to 60 seconds. Similarly, participants in the Martin et al. (2003) study were encountering a ProM cue every 120 seconds. As explained earlier, the difficulty with this approach is that repeated responding to ProM cues ensures that the ProM plan remains in participants' consciousness and that the performance index no longer reflects ProM Proper but rather vigilance/monitoring.

Low reliabilities ensure null effects and small effect sizes

In general, a large measurement error associated with unreliable measures increases the variability of observed scores, decreases the likelihood of finding statistically-significant effects, and results in smaller variability-based indexes of effect size. Whereas reliabilities of many standard word list memory tests have been established and are generally high, typically ranging from 0.70 to 0.80, reliabilities of the various prospective memory tasks are mostly unknown. Only a few studies have attempted to examine the reliability of prospective memory scores, and the results of these studies are not encouraging. To illustrate, Einstein et al. (1997) found that reliability, assessed by a correlation between two blocks of trials, each based on two ProM cue presentations, was only 0.46. However, this correlation was computed using all participants regardless of specific experimental conditions and reflects not only the reliability of measurement but also large differences in performance among experimental conditions. The actual reliability of Einstein and McDaniel's task is unknown; it may be higher, lower, or even the same. Thus, the extent to which observed scores on most of the prospective memory tasks reflect random measurement error or variability in true abilities is unknown.

If prospective memory measures are less reliable than retrospective memory measures, age-related differences (indeed, differences due to any manipulations) in prospective memory will be more difficult to find due to larger standard deviations and greater dispersions of observed scores. Moreover, the error-inflated variability in observed scores will reduce effect size indexes based on variability (i.e., d, r, r^2, η^2, etc.) and underestimate the magnitude of age-related declines in prospective memory. Finally, a lack of reliability will underestimate any relation between performance on prospective memory tasks and other measures of cognition, such as indexes of processing resources, measures of frontal functions, and intelligence. In turn, unknown reliabilities of prospective measures make many interpretations of the magnitude of age effects (except those expressed as a simple difference between two proportions) and strengths of relations between prospective memory and other aspects of cognition superfluous and any derived theoretical claims questionable.

Many studies include age-related confounds

A number of studies frequently cited as evidence of no age decline in ProM have incorporated into their design age-related confounds that most likely improve performance of older adults, decrease performance of younger adults, and consequently minimize age-related differences on ProM tasks (studies with age confounds). First, many investigators have made the ongoing task easier for older adults (e.g., Cherry & LeCompte, 1999; Cherry et al., 2001; Einstein et al., 1990, 1992, 1995, 2000; McDaniel et al., 2003; Reese & Cherry, 2002). Second, Cherry and LeCompte (1999) and Reese and Cherry (2002) compared highly intelligent older adults with low intelligence younger adults. To the extent that intelligence is positively related to performance on ProM tasks as observed by these authors, any claims about effects of age in these studies are confounded by an intelligence difference between the age groups.

Moreover, several studies have failed to ensure that the experimental conditions were the same for both younger and older adults and that younger and older adults were comparable on important participant characteristics (studies with other confounds). In several studies (Cockburn & Smith, 1994; Martin et al., 2003; Kliegel et al., 2000), participants were to ask for their belonging at the end of the experiment, and different participants gave experimenters different items. Mantyla and Nilsson (1997) conducted a population-based study of ProM, and inspection of participant characteristics reveals that those in their older groups frequently scored within the impaired range on the Mini Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975).

These age-related confounds are certain to reduce the magnitude of the observed age-related declines; failing to recognize such confounds will result in incorrect conclusions about the size of age-declines (see discussion below and Figure 4).

Age declines are larger on ProM Proper than on vigilance

Based on the theoretical distinction between ProM Proper and vigilance/monitoring, we might expect larger age effects on tasks indexing primarily ProM Proper than on tasks indexing primarily vigilance/monitoring, at least to the extent to which noticing and recognizing the relevance of the ProM cue to the previously formed plan requires processing resources.

Any quantitative analysis of previous research, however, is complicated by severe ceiling effects as well as by other methodological problems already discussed. To the extent that ceiling effects are more frequent in

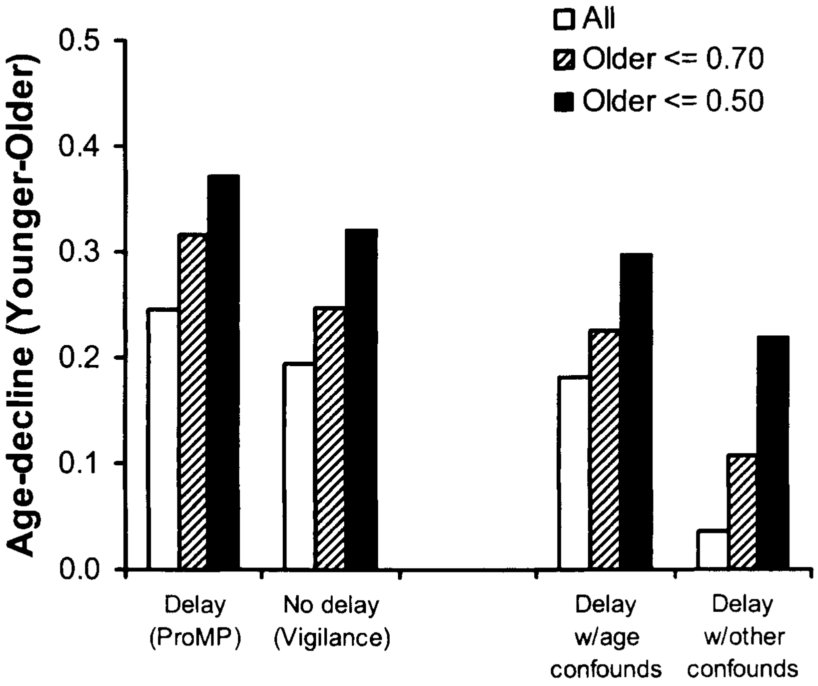

Fig. 4. Mean age declines observed in previous research. The left panel shows the mean age decline observed in conditions that incorporated a delay between ProM instructions and ProM test phase (Delay) vs conditions that included no such instruction-test delay (No-Delay) and did not confound age with other experimental or participant variables. The right panel shows the mean age decline observed in conditions that included an instruction-test delay but also included age-related confounds benefiting older adults (Delay with age confounds) and conditions that included other confounds (Delay with other confounds). Three means for each type of condition are shown: The first mean includes all age comparisons; the second mean includes only conditions where performance of older adults was equal to or below 0.70; and the third mean includes only conditions where performance of older adults was equal to or below 0.50.

studies focusing on either ProM Proper or vigilance/monitoring, the comparison of age effects in these two subdomains of ProM may be confounded by ceiling-limited scores.

The left panel of Figure 4 shows the mean age decline observed in conditions that incorporated a delay between ProM instructions and the start of the ProM test phase (Delay) vs conditions that included no such instruction-test delay (No-Delay) and did not confound age with other experimental or participant variables. The Delay group includes conditions that allowed the plan to leave consciousness, and therefore, are the most likely to measure ProMP (Cohen et al., 2001; Dobbs & Rule, 1987; Einstein et al., 1995; Graf et al., 2002; Huppert et al., 2000; Kliegel et al., 2000; Martin et al., 2003; Rendell & Craik, 2000; Rendell & Thomson, 1999; Tombaugh et al., 1995; Uttl et al., 2001; West, 1988). The No-Delay group includes conditions that most likely measure vigilance/monitoring rather than ProMP (Cohen et al., 2003; d'Ydewalle et al., 1999; d'Ydewalle et al., 2001; Einstein et al., 1997; Kidder et al., 1997; Logie et al., 2004; McDermott & Knight, 2004; Mantyla, 1993; Maylor, 1994, 1996, 1998; Maylor et al., 2002; Park et al., 1997; Vogels et al., 2002; West et al., 2003; West & Craik, 2001).

Figure 4 shows three means for each type of task: the first mean includes all age-comparisons, the second mean includes only conditions where performance of older adults was equal to or below 0.70, and the third mean includes only conditions where performance of older adults was equal to or below 0.50. As expected from the analyses shown in Figure 2, age declines are larger when condition means are less limited by ceiling effects, giving age effects a chance to emerge. More importantly, the figure shows that age declines are larger on ProMP than on vigilance, highlighting the distinction between the two ProM subdomains (see also Brandimonte, Ferrante, Feresin, and Delbello, 2001).

The right panel of Figure 4 shows the mean age decline observed in conditions that have included an Instruction-Test Phase Delay (i.e., indexing primarily ProMP) but have also included age-related confounds benefiting older adults, as well as other confounds (see the earlier section). As expected, age declines are smaller in conditions with age confounds benefiting older adults (Delay w/age confounds) than in Delay (ProMP) conditions. The mean age declines in Delay with other confounds conditions are difficult to interpret for at least two reasons. First, the effect of these confounds is unclear and second, only a few conditions are included in this group of conditions.

Section Summary

In light of the preceding review and the evidence summarized in Figures 2 and 4, the notion that older adults perform as well as younger adults on prospective memory tasks is incorrect. Rather, the previous research indicates that both ProMP and vigilance show substantial declines with aging, and that these declines have been underestimated in a large portion of the previous studies due to methodological shortcomings such as ceiling-limited scores and age confounds in research design. Indeed, based on the data in Figure 2, one might wish to claim that the strongest predictor of age declines is researchers' ability to avoid ceiling effects in measurement (Uttl, in press)!

Aging and Visually and Auditorily Cued ProM Proper

The previous research on aging and ProMP has focused exclusively on visually cued ProMP. The new study described below examines age-related changes in both visually and auditorily cued ProMP. The motivations for this study were three-fold: (1) to generalize the previous findings to a new modality, (2) to examine the notion that age-declines on cognitive tasks are related to declines in sensory functions (e.g., Anstey, Stankov, & Lord, 1993; Baltes & Lindenberger, 1997) within ProMP domain, and (3) to examine predictions about ProMP and aging using a stronger, multivariate design.

The specific aims were to examine the prediction that ProMP is more sensitive to aging then RetM, to determine if age declines in visually and auditorily cued ProMP are comparable, to examine the relation between sensory functions and ProMP, and to determine the extent to which age declines in ProMP can be explained by age declines in sensory functions and processing resources. To examine these questions, the study employed a continuous index of Visual ProMP developed in our recent research (Uttl & Graf, 1999, 2000a, 2000b, 2000c; Graf et al., 2002) and a newly developed continuous index of Auditory ProMP (Uttl & Graf, 2002).

Participants and Design

Participants were 29 younger (*M* =19.5 years, range = 18 to 22) and 36 older (*M* = 74.1 years, range = 46 to 94) adults. The younger adults were undergraduate student volunteers who participated for course credit. The older adults were volunteers recruited via newspaper advertising and word of mouth.

Table 3 shows the design of the study. Younger adults participated in only one session whereas older adults participated in two sessions separated by a one-week delay. In each session, participants' ProM was assessed once with an Auditory ProMP task and once with a Visual ProMP task.

Table 3. The study design and the sequence of critical tasks. Younger adults participated in only one session whereas older adults participated in two sessions separated by a one-week delay.

Younger	Older
Session 1	**Session 1**
...	...
ProM Instructions	ProM Instructions
VLT/U	VLT/U
A/B Card Sorting + Auditory ProMP	A/B Card Sorting + Auditory ProMP
...	...
ProM Instructions	ProM Instructions
...	...
A/B Card Sorting + Visual ProMP	A/B Card Sorting + Visual ProMP
...	...
	Session 2 (one week after Session 1)
	...
	ProM Instructions
	VLT24/RA
	A/B Card Sorting + Auditory ProMP
	...
	ProM Instructions
	...
	A/B Card Sorting + Visual ProMP

Procedure

Participants were tested individually as part of a larger study on cognitive aging. Testing took place in a quiet room with ambient noise levels below 45 dB. All visual stimuli were presented on a 17-inch Sony Trinitron Flat Screen monitor and all auditory stimuli (except pure tones for testing auditory acuity) were presented using a pair of high-quality Yamaha speakers. Young participants were tested in a single session lasting about 1.5 hours whereas older participants were tested in two 1.5 to 2 hour long sessions scheduled one week apart. The order of critical tasks was fixed as shown in Table 3 only the assessment instruments relevant to the present report are described below.

Visually Cued ProMP. The index employs ProM cues (pictures) whose intrusiveness (i.e., size) increases over time to the point of being almost impossible not to notice and the dependent variable is the cue size when a participant responds to it. During the ProM instruction phase,

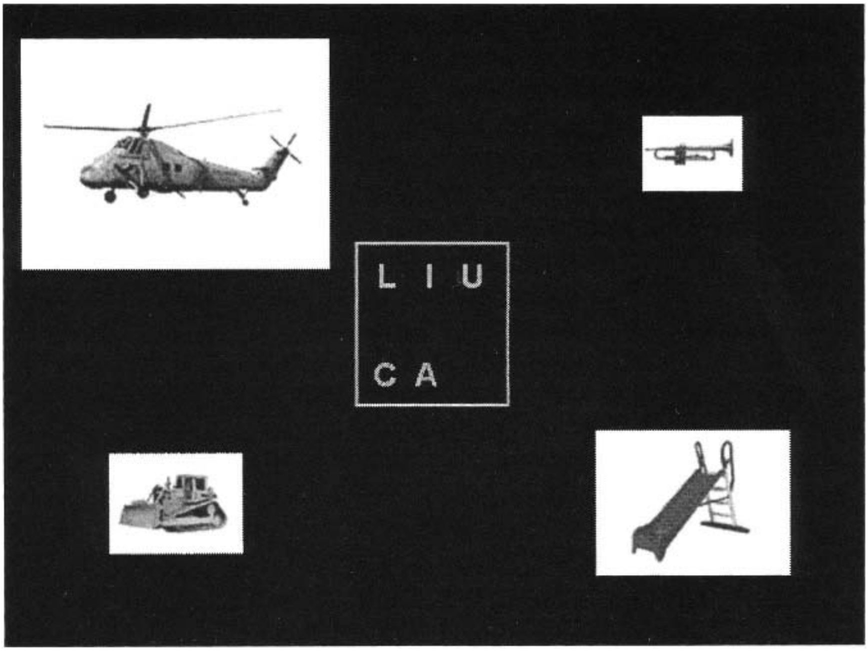

Fig. 5. An example of the material displayed for the A/B Card Sorting task and for assessing ProM on Visual ProMP. In the actual experiment, pictures were presented in color.

participants are shown the ProM cue and told to stop whatever they are doing when they notice the ProM cue anytime and anywhere during the experiment. During the ProM test phase, participants are engaged in an attention-demanding ongoing task – sorting cards displayed on a computer monitor by pressing either left or right arrow keys. While sorting the cards, pictures of common objects appear in various sizes in the 4 corners of the screen; the pictures are replaced by different pictures with each key press. The size of each picture is determined randomly from trial to trial within the specified range. The ProM cue appears at random among these pictures. If a participant fails to notice the ProM cue, it appears again a few trials later, but this time in a larger size. The cue grows larger across trials until a participant responds to it or until a maximum size is reached. A sample display is shown in Figure 5. In a series of experiments, we have demonstrated that this method provides a valid and reliable index of ProM Proper in both young and older adults (Uttl & Graf, 1999, 2000a, 2000b, 2000c; Graf et al., 2002).

Auditorily Cued ProMP. A newly-developed continuous index of Auditory ProMP is based on the same idea: The ProM cues are sounds whose intrusiveness (i.e., loudness) increases over time to the point of being difficult not to notice, and the dependent variable is the cue loudness when a participant responds to the cue. Specifically, participants are played a ProM cue – a camera clicking or the sound of a car horn – and are told to stop whatever they were doing when they notice the ProM cue anytime and anywhere during the study. In the experiment, participants are engaged in the same card sorting task used for assessment of Visual ProM Proper. While sorting the cards, digitized natural sounds (e.g., water running, door bell) are played from the speakers via a SoundBlaster card. The loudness of the sounds is determined at random within the specified range. The ProM cue appears at random among these sounds. If a participant fails to respond to the ProM cue, the cue appears again a few trials later, but this time louder. The cue becomes louder across trials until the subject detects it or until the maximum loudness is reached. Preliminary findings with undergraduate students showed that this new Auditory ProM Proper index is reliable (test-retest reliability $r = .81$) and only weakly correlated with measures of retrospective memory ($r < .30$), thereby demonstrating divergent validity in college students (Uttl & Graf, 2002).

Explicit RetM. Explicit RetM was assessed using two verbal learning tests (VLT) patterned after the Rey Auditory Verbal Learning Test (RAVLT; Rey, 1964; Spreen & Strauss, 1998). The first VLT included lists of 20 unrelated words (VLT/U); the second VLT included lists of 24 related words selected from four different categories (VLT/R). Both tests were administrated according to the instructions for the RAVLT published in Spreen and Strauss (1998) except that only three study-test trials were given instead of five.

Visual Acuity. Far and Near visual acuity was assessed with standard Snellen charts. Far Visual Acuity (FVA) was measured from a distance of 3m; Near Visual Acuity (NVA) was measured at reading distance of 40cm. All measurements were taken with participants' presenting optical corrections and converted to LogMar equivalents (Holladay, 1997).

Auditory Acuity. Air-conducted auditory pure-tone thresholds (dB) were obtained for five different frequencies: 250, 500, 1000, 2000, and 4000 Hz.

Processing Capacity. Processing capacity was measured by the A/B card sorting task (Uttl, Graf, & Cosentino, 2000).

Vocabulary. Participants' vocabulary knowledge was assessed using a shorter version of the North American Adult Reading Test called NAART35 (Uttl, 2002) that requires participants to pronounce 35 English words with irregular spelling.

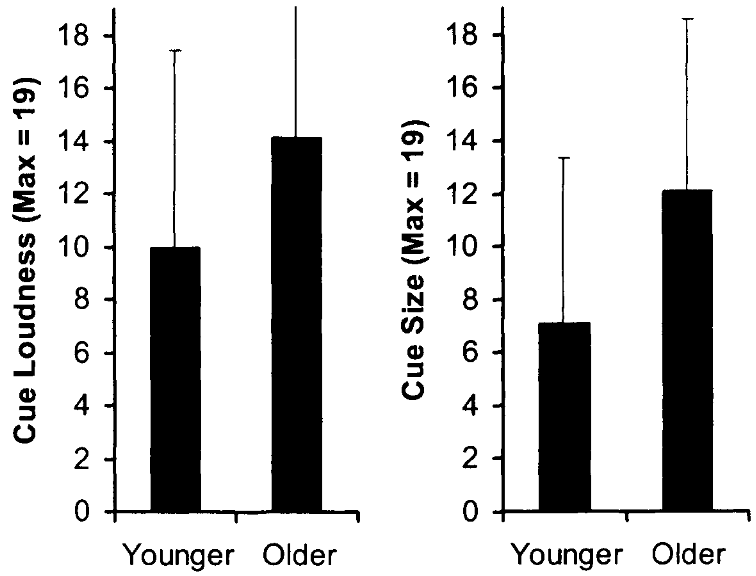

Fig. 6. Mean cue loudness required for ProMP response on Auditory ProMP (left panel) and mean cue size for Visual ProMP (right panel). Error bars represent one standard deviation.

Results and Discussion

Two sets of analyses were conducted. The first set of analyses compares performance of younger and older adults (between-groups analyses). The second set of analyses focuses on correlational analyses within the older adult group that take advantage of more reliable measurement of ProMP due to multiple assessments of both Auditory and Visual ProM within the older adult group (within older-group analyses).

Between Group Analyses

Consistent with extant results from prior RetM research, older adults recalled fewer words than younger adults on all trials; older adults also recalled fewer words ($M = 6.1$, $SD = 3.6$) than younger adults ($M = 8.7$, $SD = 2.8$) after a 20-minute delay, $t(63) = 3.24$, $p = 0.002$. More importantly, Figure 6 shows participants' performance on the two indexes of ProMP.

Table 4. Correlations within older adults.

	1. Age	3. FVA	4. NVA	5. Hear	6. Aud ProM	7. Vis ProM	8. VLT/U LDR
1. Age							
3. FVA	0.29						
4. NVA	**0.40**	**0.57**					
5. Hear	**0.62**	0.29	0.21				
6. Aud. ProM	**0.62**	**0.44**	0.33	**0.39**			
7. Vis. ProM	**0.57**	**0.47**	0.31	0.16	**0.63**		
8. VLT/U LDR	**-0.47**	**-0.36**	**-0.53**	**-0.42**	**-0.59**	**-0.39**	
10. CS	**0.65**	**0.40**	**0.43**	**0.49**	**0.61**	**0.49**	**-0.52**

Note: FVA = Far Vision Acuity (logMar); NVA = Near Vision Acuity (logMar); Hear = better ear Hearing Level (dB); VLT/U LDR = Verbal Learning Test with unrelated words, 20-min. Long Delay Recall (#correct); CS = A/B Card Sorting (ms). Correlations printed in bold are significant with $p < 0.05$.

Compared to younger adults, older adults required larger cues on the Visual ProMP tests, $t(63) = 3.26$, $p = 0.002$, and louder cues on the Auditory ProM test, $t(63) = 2.59$, $p = 0.012$.

Within older-group analyses

Visual ProMP, Auditory ProMP, RetM, and Aging. Table 4 shows correlations between age, visual and auditory acuity, Visual and Auditory ProMP, RetM, and processing resources. Consistent with well-established prior research findings, free recall of unrelated words after a 20-minute delay was negatively correlated with age, $r = -.47$. This age-related decline in retrospective memory was obtained on all recall trials. More importantly, the analyses of ProMP performance revealed strong age-related declines in both Visual and Auditory ProMP, $r = 0.57$, $p < 0.05$, and $r = 0.62$, $p < 0.05$, respectively. In combination, these findings suggest that age-related declines on the indexes of ProMP are larger than age-related declines on free recall retrospective memory tests.

ProMP, RetM, and Processing Resources. Table 5 shows the results of hierarchical regression analyses aimed to elucidate the relative contribution of processing resources to age declines on ProMP indexes vs RetM. The data in the table show that A/B Card Sorting, an index of processing resources, explained similar proportions of overall variability in RetM and Visual ProMP but a larger proportion of variability in Auditory ProMP.

Table 5. Hierarchical regression analyses.

	Visual ProM		Auditory ProM		RetM	
	Δr^2	R^2	Δr^2	R^2	Δr^2	R^2
Age only						
Age	**.32**	**.32**	**.39**	**.39**	**.23**	**.23**
Resources + Age						
1. A/B Card Sorting	**.24**	**.24**	**.37**	**.37**	**.27**	**.27**
2. Age	**.11**	**.35**	**.09**	**.46**	.03	--
% Age	66		77		87	
Sensory systems + Age						
1. Vision	**.23**	**.23**				
2. Hearing	--	**.23**				
1. Hearing			**.16**	**.16**	**.17**	**.17**
2. Vision			**.12**	**.28**	**.20**	**.37**
3. Age	**.21**	**.43**	**.19**	**.47**	.02	--
% Age	34		51		91	

Note: Values printed in bold are significant with $p < 0.05$.

More importantly, A/B card sorting explained the largest amount of age-related variability on RetM and smaller amounts on Auditory ProMP and Visual ProMP.

ProM, RetM, and Sensory Functions. The next set of analyses was designed to elucidate the contribution of sensory functioning to performance on ProM Proper and RetM. Consistent with extant prior research (Botwinick, 1967; Fozard, 1990), the hearing data revealed substantial age-related declines in pure tone auditory acuity; the tones had to be louder for older adults than for younger adults, $r = 0.62$. Similarly, the visual acuity data showed large age-related declines in both Near and Far Visual Acuity, with older adults requiring larger print than younger adults, $r = 0.29$, and r = 0.40, respectively (see Table 4).

Table 5 shows the results of hierarchical regression analyses aimed at determining whether these age-related declines in sensory functions mediated age declines in Visual and Auditory ProMP as well as in RetM. These analyses show that although sensory functions explained all or almost all age-related variability in RetM, they explained only 34% and 51% of age-related variability in Visual ProMP and Auditory ProMP, respectively.

Section Summary

The findings from this study demonstrate that both Visual and Auditory ProMP decline with age and suggest that the magnitude of age-related declines in Visual and Auditory ProM Proper are larger than declines in RetM. Although processing resources explain all or almost all age-related declines in RetM, they explain only a part of age declines in ProMP. Similarly, whereas age-related declines in sensory functions account for all or almost all of age-related declines in RetM, they account for only 34% of age declines in Visual ProM and only about 51% of age declines in Auditory ProM.

Conclusions

Graf and Uttl (2001) have argued that ProM is best divided into several subdomains, with ProMP, vigilance, and habitual ProM as parallels to episodic, short-term, and semantic memory in the RetM domain. The quantitative review of prior research shows substantial age-related declines on both ProMP and vigilance/monitoring tasks. Moreover, the review reveals more pronounced age declines on ProMP than on vigilance/monitoring tasks, supporting the distinction between these two subdomains of ProM and illuminating one possible source of confusion regarding the magnitude of age-related declines on ProM. Consistent with the dynamic competition for limited processing resources between ProM and ongoing task demands, the research review also revealed that age declines were smaller when the ongoing task was made easier for older vs younger adults or when studies compared much more intelligent older vs younger adults. These findings are similar to those observed in the RetM domain showing that age declines in RetM can be minimized when older vs younger adults are given more study time or when more intelligent older adults are compared to less intelligent younger adults.

Perhaps the most striking new finding showed that the best predictor of age declines in ProM is researchers' success in avoiding ceiling effects. Of course, this finding tells us little about processes involved in ProM but it calls (or should call) our attention to the methods we are using in this relatively new research field. The finding underscores the necessity to develop better methods for assessing ProM.

The new research findings showed large age-related declines on Visual ProMP and extended the previous research by showing large age-related declines in Auditory ProMP. Moreover, similar to the RetM domain, portions of these age declines in ProMP can be explained by processing resources and by sensory functions. In contrast to RetM, however, a substantial portion of age declines in ProMP remains unexplained by processing resources or by sensory functions. In combination, the review of prior research and the new research findings are consistent with Craik's (1983, 1986) prediction of substantial age declines on ProMP tasks, and they highlight the importance of processing resources and degradation in sensory functions in mediating age declines in ProMP.

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Prospective Memory Retrieval Revisited

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Summary. Prospective memory is the ability we use to formulate intentions, to make plans and promises, and to retain and execute them at the appropriate place or time. Like retrospective memory, prospective memory serves many different functions (e.g., short-term, long-term). This chapter deals with one of them—with episodic prospective memory, the function which is analogous to episodic retrospective memory. An analysis of what is required for the context-appropriate successful retrieval of a previously formed plan reveals three basic steps or stages: cue noticing, cue identification or singularization, and plan recollection. In separate sections of the chapter, I discuss the cognitive processes that appear to mediate each of these stages. I use the well-entrenched theoretical prospective memory models by Craik (1986) and by Einstein and McDaniel (1996) as foils. They also provide a convenient platform for differentiating new theoretical assumptions from those that define the field's current understanding of the processes involved in the context-appropriate recollection of previously formed plans. In support of the new assumptions introduced here, the chapter also reports the results of several recent empirical investigations.

Key words: Prospective memory, cue noticing, cue singularizing, discrepancy detection, task interruption, attention switching

Introduction

"Good intentions are not good enough; ultimately we are measured by our actions." Anonymous

"The road is long from the intention to the completion." Jean Baptiste Molière (1622-1673)

The ability to formulate intentions, to make plans and promises, and to retain and execute them at the appropriate place and time is generally known as prospective memory (ProM). Like retrospective memory (RetM), memory's prospective function is required for a large variety of tasks and activities. For some of them, such as when the intent is to pick up groceries on the way home from work or to convey a message to a colleague the next time we meet, there can be a substantial delay between making a plan and executing it. In these latter situations, the plan is not likely to be held in consciousness throughout the retention interval; thus, it needs to be brought back into conscious awareness when the opportunity arises for executing it[1].

How does the context-appropriate conscious re-instantiation of a previously formed plan or intention come about or, in keeping with Molière, what happens on the long road from intention to completion? This question has stimulated a large number of empirical investigations and theoretical claims. It has also inspired two prominent theoretical proposals, the noticing-and-search model by Einstein and McDaniel (1996) and the resource model by Craik (1986). These models have been valuable in placing ProM research on a more solid theoretical foundation. However, they were never intended as complete theories of ProM and consequently provide only limited insight into how the context-appropriate conscious re-instantiation of a previously formed plan or intention comes about.

My goal for this chapter is to augment the existing models, and to prepare the path for creating a more complete theoretical account of ProM task performance which highlights the dynamic interaction among the processes that are recruited for the conscious re-instantiation of a previously formed plan. To set the stage for this undertaking, the chapter begins with a few definitions and provisos, and with a task analysis, a detailed examination of the retrieval-phase steps or stages that are required for the successful recollection and completion of a previously formed plan. Next, the core of the chapter consists of three sequentially related sections, each focusing on the cognitive processes that seem implicated by one of the retrieval phase stages. To facilitate understanding and to distinguish my new theoretical claims and assumptions from existing ones, I shall use the models by Einstein and McDaniel (1996) and by Craik (1996) both as conven-

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[1] We (Graf & Uttl, 2001) have used the label "ProM proper" for the distinct cognitive function that serves these prospective activities, that is, activities where a plan needs to be brought back into consciousness at the time of retrieval. We used the adjective "proper" in the same manner as William James (1890, p. 684) who in connection with retrospective memory stipulated that "memory proper" requires "the knowledge of an event, or fact, of which meanwhile we have not been thinking, with the additional consciousness that we have thought or experienced it before."

ient points of departure and as foils. In a final section, I shall briefly report the results of recent investigations that have been inspired by some of the theoretical options that are featured in this chapter.

ProM tasks: Provisos

Not all prospective memory activities are alike, and thus, to facilitate communication, researchers have proposed a number of labels to distinguish, for example, among monitoring, ProM proper, and habitual ProM. Monitoring describes the dual-task situation that occurs, for example, in the course of a conversation when we concentrate on what to say after another person stops speaking or when we carry on with other activities while waiting for the water to boil. In monitoring activities, intentions are consciously held throughout the retention interval, and thus they raise no questions about the context-appropriate re-instantiation of previously formed plans and intentions. By contrast, in the case of the prospective activities that are the focus of the present chapter, there often is a long delay between making a plan and executing it, and because subjects' attention is generally focused elsewhere (i.e., on unrelated activities) during this delay, these tasks require that a previously formed plan is brought back into conscious awareness at the time of retrieval.

Kvavilashvili and Ellis (1996) have used the word "episodic" to identify this particular type of prospective memory task. The episodic label highlights the fact that some prospective activities are concerned with one-time events, plans, or activities, and by virtue of this feature they are different from tasks that need to be executed repeatedly, for example, to take medication according to a prescribed schedule. Meacham (1982), Meacham and Leiman (1982), and Harris (1984) have used the label "habitual" in connection with the latter ProM activities. The similarities and differences between episodic and habitual ProM tasks have been explored and discussed elsewhere (Harris, 1984; Kvavilashvili & Ellis, 1996).

Both episodic and habitual tasks involve the context-appropriate conscious re-instantiation of previously formed plans and intentions, but there are numerous differences in how this re-instantiation is achieved in the two cases (Ellis, 1996; Kvavilashvili & Ellis, 1996). For this reason, and to keep the present chapter focused, I shall consider here only episodic tasks. But even this domain is relatively large. It spans field and laboratory research as well as research on plans and intentions that were generated by subjects versus generated by others (e.g., experimenters, teachers, parents). A small number of field studies have explored memory for self-generated plans (Andrzejewski, Moore, Corvette, & Herrman, 1991; Ellis & Nimmo-Smith, 1993), but most investigations have relied on laboratory methods to explore subjects' ability to carry out plans and intentions that were experimenter-assigned. The focus of this chapter is on a subset of the latter investigations, specifically those where the occasion for retrieval is a clearly predefined event (e.g., the display of a specified stimulus, the occurrence of specified action, the termination of an event) rather than an amount of elapsed time (e.g., in 20 minutes) or a defined clock time (e.g., at 3 pm)[2].

An analysis of episodic ProM task retrieval

Einstein and McDaniel (1990) have introduced a simple laboratory method for investigating performance on event-cued episodic ProM tasks. The method includes three phases: a planning or instruction phase, a retention phase, and a test or retrieval phase. For a concrete illustration of these phases, consider a recent study where we informed subjects at the beginning of the experiment that they would "be shown animal words at some point during the experiment, and that if [they saw] one of those words, [they should] stop whatever [they were] doing and press the q-key [a designated key] on the computer keyboard" (Savchuck, Khan, Lee, & Graf, 2004). Following these instructions, during the retention phase, we occupied subjects with a series of paper and pencil tests, required them to learn a long list of common words for a subsequent recognition memory test, and then engaged them in more paper and pencil tests. About 20 minutes after giving the prospective task instructions, we administered an old/new recognition memory test for the previously studied words, and the animal words mentioned in the ProM task instructions were embedded in the test list.

In our experiment, subjects were expected to execute the previously assigned prospective task in response to the display of each animal word; thus, these words functioned as ProM task retrieval cues. The nature of these cues has been manipulated along various dimensions in previous investigations (e.g., modality, distinctiveness, typicality), revealing that not all cues are equally effective in bringing about the successful completion of planned activities (for review see Brandimonte, Einstein, & McDaniel, 1996). Moreover, previous work has shown that the effectiveness of a ProM task cue depends not only on its own properties, but also on proper-

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[2] The labels "event-based" and "time-based" are often used to mark the difference between these two types of ProM tasks (Einstein & McDaniel, 1990, 1996).

ties of the local or proximal context in which it is presented. In our experiment, the local context was defined, in part, by the list of common words we displayed for the old/new recognition memory test, and the requirements of this test defined a unique activity context for the execution of the planned task. The label *ongoing task* is commonly used as a shorthand descriptor for the activity context in which ProM tasks must be carried out. Not surprisingly, the properties of the ongoing task have a powerful influence on ProM task performance (Einstein, Holland, McDaniel, & Guynn, 1992; Einstein & McDaniel, 1990; Graf, Uttl, & Dixon, 2002; Jacova, 2003; Marsh, Hancock, & Hicks, 2002; Zhao & Yang, 2002).

This brief description serves to focus attention on the retrieval-phase steps or stages that are required for the successful completion of an episodic ProM task. Because success on the task depends on the context-appropriate recollection of a previously formed plan, this process must be initiated or triggered by the occurrence of the designated cue or event. To have this triggering effect, the cue must first be noticed, in the sense of being focally attended or perceived as a distinct stimulus or event. But noticing is not enough; the cue must also be identified as special, as different from other items presented in the course of the ongoing task, as relevant to the previously formed plan. And, in turn, the memory representation of that plan must be accessed and brought into consciousness. Under laboratory testing conditions, the cue appears as part of the ongoing task, and this task is likely to command subjects' focal attention. Therefore, the ongoing task must be interrupted (i.e., the attention-capture of the ongoing task must be broken), and attention must be disengaged from it and switched to the ProM task.

In the following three sections of this chapter, I shall consider each of these retrieval phase steps or stages in detail, as well as discuss how they are handled by Einstein and McDaniel's (1996) notice-and-search model and by Craik's (1996) resource model. I will propose additions, modifications, and alternative theoretical assumptions where either intuition or evidence seems to require them.

The existing versions of the notice-and-search model and of the resource model, or the revisions proposed in this chapter, do not constitute a complete theory of the context-appropriate recollection of previously formed plans because the last stage considered here, switching attention to a consciously retrieved previously formed plan, does not guarantee the successful completion of a ProM task. It is often the case that a person realizes that they had planned to do something in the context of a particular cue (e.g., give a message to a colleague at the next meeting) yet they fail to remember what they had planned to do[3]. The distinction between these two aspects of task performance has be described as remembering *that* we had planned to do something and remembering *what* we had planned to do (Dobbs & Rule, 1987; Einstein et al., 1992; Uttl, Graf, Miller, & Tuokko, 2001). When we become aware that we had planned to do something in a particular context but cannot remember what we had planned, it may be that we search memory in the same manner as we would for an explicit episodic RetM task. For this reason, remembering *what* has been labeled the retrospective component of a ProM task, thereby distinguishing it from the remembering *that*, or prospective component (Einstein et al., 1992). The present chapter focuses mainly on how the prospective component of ProM tasks is accomplished and only in a limited way addresses the cognitive processes implicated by the retrospective component.

ProM cues must be noticed

Prospective memory research is still in the pre-theoretical stage (Tulving 1985), largely driven by empirical questions, by what-if questions (e.g., I wonder what would happen if), and by assumptions adapted from other research areas (e.g., attention, perception, episodic memory). However, the notice-and-search model by Einstein and McDaniel (1996) has marked a welcome departure from this approach and has inspired more theoretically focused research. According to this model, successful recollection of a previously formed plan involves two stages: noticing and searching. By noticing, Einstein and McDaniel seem to mean realizing that a cue is special in some sense, is oddly familiar. In contrast, they conceptualize searching as a subsequent process, as a systematic attempt to find an interpretation for what the cue might mean in its current context and, when successful, this process is assumed to bring about the conscious reinstantiation of a previously formed plan. Einstein and McDaniel postulate that noticing is an automatic process whereas search is an attention-demanding controlled process; consequently, because noticing occurs automatically, "good prospective memory [task performance] depends on the success of the directed search process" (Einstein & McDaniel, 1996, p. 122).

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[3] The need for distinguishing between remembering a plan and performing a planned task also arises because of changes that might have occurred between the planning and retrieval phases in priorities, in interest, in motivation, in circumstances, etc.

Consistent with the task stages identified earlier in this chapter, and inspired especially by empirical and theoretical work on attention, it seems both possible and necessary to go beyond the two stages of the notice-and-search model. My starting point for extending the model is its first stage, the cue noticing stage, because the word *noticing* has multiple meanings that seem to capture important aspects of episodic ProM task performance beyond the scope of the Einstein and McDaniel model.

Noticing something may be interpreted as perceiving it as a distinct, unique stimulus, event, or occurrence, as paying attention to it at least momentarily. By this definition, it is apparent that the cues given for RetM tasks almost never go unnoticed[4]. For all RetM tasks, the instructions given at the time of retrieval draw subjects' attention to the cues; they are designed to help subjects focus on and understand the function of the cues as well as their relation to the to-be-remembered items. By contrast, for episodic ProM tasks, no prospective task relevant instructions are given at the time of retrieval (Graf & Uttl, 2001), and for this as well as other reasons, it is common for ProM task cues to remain unnoticed.

Consider the everyday example where the plan is to buy groceries en route home from work. Unforeseen circumstances, such as a colleague asking us for a ride home or a traffic jam, might cause us to choose a route that does not go by the supermarket. Or, if the plan is to give a message to a friend we expect to see at a party, that friend may not attend the party. Being distracted is yet another reason for why we may fail to notice a cue. At the party, we may be engaged in an intense conversation with others and thus never notice our friend.

At least some of these conditions for failing to notice ProM cues are directly relevant to the laboratory methods that have been used to explore episodic ProM task performance. Consider a study by Maylor, Darby, Logie, Della Sala, and Smith (2002) in which the subjects, children between 6 and 11 years of age, were shown photographs of teachers, the ongoing task being to name each teacher. The study examined the children's performance on two different ProM tasks. For one of them, the subjects were required to indicate which teachers were wearing glasses; for the

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[4] Of course, there are exceptions to this rule, for example, in experiments on recognition failure of recallable words (Muter, 1978; Tulving & Thomson, 1973). In such experiments, a to-be-remembered word may not be noticed because it is presented in a different interpretive context during the study and test phase. For example, *jam* may not be noticed on a test if it is shown together with *strawberry* but was presented together with *traffic* at study. Similarly, a word may not be noticed when it appears by itself at study (e.g., *ball*) and as part of a compound (e.g., *baseball*) at test.

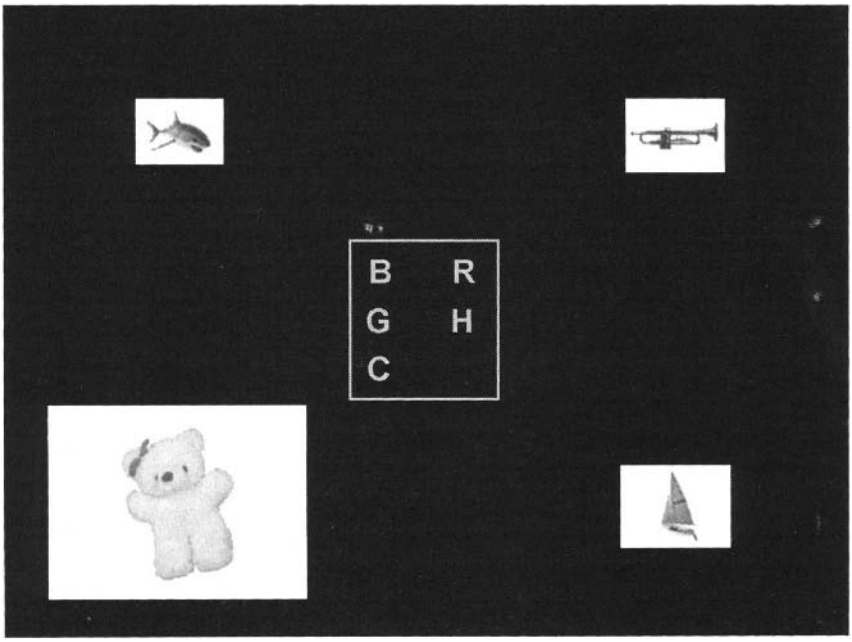

Fig. 1. The figure, adapted from Graf, Uttl, and Dixon (2002), illustrates the manner in which the materials required for the ongoing task and for the episodic ProM task were presented to subjects. For the ongoing task, subjects were required to make A/B decisions about each card that was displayed in the center of the screen. For the episodic ProM task, subjects were required to press a designated key if "ever in the course of the experiment you see a picture of a teddy bear." The picture of the teddy bear (i.e., the ProM cue) appeared on about every fifth trial of the ongoing task, each time in a different quadrant of the screen. The size of the cue increased across trials.

other, they were required to indicate if there was a plant in the periphery of the picture. The results showed that children were more likely to succeed on the ProM task when the cues were presented centrally rather than peripherally, presumably because the ongoing task ensured that the former but not the latter cues would be noticed. Uttl and Ohta (2004) have replicated and extended this finding in a study with young adult subjects.

Whether a ProM cue is noticed and thus is effective in triggering retrieval of a planned task is determined not only by its spatial location, however, but also by its other physical properties (e.g., size, brightness, loudness, motion) and by its local context. In several recent studies (Graf et al., 2002; Jacova, 2003; Uttl & Graf, 1999), we presented subjects with playing-card sized displays, each showing either the letter A or B, together with a varying number of irrelevant additional letters. The ongoing task required making an A/B decision about each card. Each of the stimulus cards was displayed in the center of the computer monitor at the same time as pictures of common objects (e.g., car, table, horse) were shown in each corner of the monitor, as illustrated in Figure 1. The ProM task was to press a previously designated key "if ever in the course of the experiment you see a picture of a teddy bear [one of the ProM cues]." The experiment had a large number of trials, with a new stimulus-card and peripheral pictures shown on each trial. Each ProM cue was shown repeatedly, on about every 5th trial on average, each time in a randomly determined quadrant of the screen. Across presentations, we increased the size of the ProM cue, so that it measured 98 x 72 pixels on its first presentation versus 336 x 252 pixels at is maximum size.

Not surprisingly, the results revealed subjects' success rate on the ProM task increased with the display size of the cue[5] (Graf et al., 2002). In a clever extension of this method, Uttl (2004, also this volume) has recently demonstrated a similar relation between performance on a visual ProM task and auditorily presented cues that varied in loudness.

By contrast to the foregoing experiments, where the ProM cues and the stimuli for the ongoing task were presented either in different spatial locations or in different sensory modalities, these cues have been presented in the same spatial location and sensory modality for the vast majority of previous laboratory investigations, typically in conjunction with an ongoing task which ensured that each cue was noticed—perceived as a distinct entity—at least briefly. The latter situation is illustrated by our recent study where the ProM cues were embedded in a long list of common words forming the recognition test list, and where the ongoing task required subjects to make an old/new recognition decision about each word (Savchuck, Khan, Lee, & Graf, 2004). But even this stimulus/cue presentation method permits manipulations that are likely to affect the ProM cue noticing stage. It seems reasonable to assume that noticing, or the amount of attention paid to a cue, would be increased, for example, if a ProM cue and the stimuli for the ongoing task were presented in a different or unique display color, in a different format (e.g., bold, italics), or in a different size or in a different voice. Similarly, cues could be made more or less noticeable by

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[5] The results from our experiments with peripherally displayed ProM cues must be interpreted with caution because the size of the cues was confounded with the number of times each cue had been presented. The size of the display was also correlated with distance from the center of the screen (i.e., as the cue size increased, the inner edge of each picture moved closer to the center of the screen). Future research needs to assess how each of these factors affects ProM task performance.

making them stand out from their local context (i.e., the stimuli chosen for the ongoing task) by virtue of other properties such as their letter length, orthographic regularity, frequency in the language, or novelty (Brandimonte & Passolunghi, 1994; Cohen, Dixon, Lindsay, & Masson, 2003; McDaniel & Einstein, 1993; Einstein & McDaniel, 1990).

The latter method of manipulating the noticeability or distinctiveness of ProM cues was employed in a study by McDaniel and Einstein (1993). The ongoing activity required subjects to perform a series of short-term memory tasks. For each trial, a short list of words was shown and recall was tested immediately after the last word was displayed. For the ProM task, subjects had to press a designated key on the computer keyboard if they encountered a specified ProM cue. In terms of word frequency, this cue was either similar to or different from the stimuli used for the ongoing task. The results showed a facilitation effect in ProM task performance when the cues were distinct.

For some kinds of ProM task cues (e.g., a ribbon on our finger, a word displayed in red ink in the context of a list of black words), cue noticing is guaranteed such that it may be difficult if not impossible to distinguish empirically this type of processing from the Stage 1 activity described by the Einstein and McDaniel (1996) model. However, in many other situations (e.g., with peripheral cues, with cues presented in a different modality from the ongoing task materials), and with weaker distinctiveness manipulations (e.g., displaying only one letter rather than the whole word in italics), cue noticing is clearly neither guaranteed nor automatic. For this reason, it seems necessary to postulate that cue noticing is a critical step or stage en route to the successful completion of episodic ProM tasks.

As described in the foregoing paragraphs, noticing a ProM task cue seems to be primarily an achievement of attention. Most likely, this achievement is related to the attention capture phenomenon—the finding that certain stimuli are more likely than others to attract/command attention (Franconeri & Simon, 2003; Yantis, 1993)—as well as to pop-out effects in visual search (Rensink & Enns, 1995; Treisman & Gelade, 1980). In addition, the frequent failure to notice ProM cues also may be related to inattentional blindness (Mack & Rock, 1998; Whittlesea & Hughes, this volume) as well as the Kamin blocking effect, that is, the finding of impaired associative learning to previously presented/contextually-familiar cues (Kamin, 1968). Extensive research has been conducted on each of these topics. Therefore, to the extent that these topic areas are related to ProM cue noticing, the literature on them is likely to provide a wealth of methodological, empirical, and theoretical insights that may inspire new investigations of episodic ProM task performance.

ProM cues must be singularized

In the recognition test experiment described earlier in this chapter (page 308), the subjects were required to make an old/new decision about each of a long list of words, among them a few animal words, and for the concurrent ProM task they were instructed to press the q-key on the computer keyboard every time they saw an animal word. Although they attended to and made a decision about each displayed word, many subjects failed to press the q-key in response to the animal word cues. Similarly, while driving home from work each day, we may notice many events and objects, a supermarket among them, yet we might still fail to respond appropriately to the supermarket where we had intended to stop for groceries. Clearly, just noticing an event is not enough; it does not ensure that we perceive or use the event as a ProM cue, or that we succeed in retrieving a previously formed plan.

According to the model by Einstein and McDaniel (1996), the context-appropriate recollection of a previously formed plan involves two stages that follow cue noticing. First, the event serving as a ProM cue has to be identified as special in some sense; it has to be experienced as different from the other events that occur as part of the ongoing task or as different from the last time we encountered it (after all, we may have seen the supermarket where we planned to stop for groceries many times previously). Second, the experienced special status or singularity of the cue-event has to be interpreted appropriately in the context of the ongoing task[6].

In some cases, the first of these stages, detecting the singularity of a ProM cue, seems guaranteed by its very nature, because the event is rare and always signals something special. The most familiar example of this kind is the ribbon around the finger. Under laboratory conditions, the same automatic detection of an event's singularity might be achieved, for example, by presenting a ProM cue word in one color (e.g., red) in the context of other words that are all printed in another color (e.g., black). If not forewarned about and provided with a sensible, believable explanation for the occurrence of such Von Restorff-like events (Pillsbury & Raush, 1943; von Restorff, 1933), subjects would undoubtedly experience them as odd, as special in some sense. By contrast to this situation, however, in many laboratory studies the ProM cues are presented in exactly the same format (e.g., color, font size, screen location) as the materials for the ongoing task,

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[6] In Einstein and McDaniel's (1996) model, these stages are called notice and search, respectively. I am not using their terms in this chapter to avoid confusion between the retrieval stages identified in this chapter and those specified in the Einstein and McDaniel model.

and thus, the cues are distinct only by virtue of the instructions provided in connection with the ProM task. What needs to be explained is how we come to perceive these latter kinds of events as odd, as singular. How do the ProM task instructions ensure that a common event, such as a familiar word or a supermarket on our way to work, is subsequently experienced as deserving of special attention, as relevant to one of our plans?

One provocative and promising answer to this question (see Einstein & McDaniel, 1996) builds on Mandler's account of retrospective recognition memory and related memory and perceptual phenomena (1980, 1991, 1994). According to Mandler, the perceptual processing of a to-be-remembered item during the study phase produces a more integrated memory representation for that item and, as a consequence, the retrieval phase processing of the same item is facilitated. Mandler proposed that this processing facilitation is experienced as an oddity or singularity, and in the context of a recognition test, this singularity is attributed to the item's oldness. Elsewhere, Whittlesea and Williams (1998, 2001a, 2001b) have elaborated on this view and argued that people chronically appraise the fluency of their processing activities, and if those processing activities are discrepant with expectations, they (people, subjects) try to find a cause for the discrepancy (see also Whittlesea & Hughes, this volume).

For a concrete illustration of this type of singularity reaction, Mandler (1980) described what might happen if we were to encounter our neighborhood butcher—a person known to us from a different context—on a commuter bus. While scanning the faces of the people around us, the butcher's face would stand out (i.e., because it would be processed more fluently than the faces of strangers), causing us to do a double take, and thus to reflect on where we might have met that person previously.

More recently, Jacoby and his colleagues have demonstrated that the unexpected fluency of processing of an item provides a basis for making a variety of other high-level judgments (Jacoby, Kelley & Brown, 1989; Jacoby & Whitehouse, 1989; Jacoby, Woloshyn, & Kelley, 1989). In one particularly compelling demonstration, the subjects were exposed to names drawn at random from a telephone directory in Phase 1 of an experiment. One day later, in Phase 2 of the experiment, the previously exposed names were displayed as part of a much longer list that included both famous names and not-previously exposed non-famous names, and subjects were required to rate the famousness of each name. The results showed that the names pre-exposed on Day 1 were rated as more famous than the new, not previously exposed, non-famous names. Jacoby and his colleagues explained this finding by arguing that the pre-exposed names were processed more fluently in Phase 2 of the experiment, and that subjects (mis)interpreted this unexpected fluency of processing as fame.

The general claim that people chronically appraise the fluency of their processing activities and react if those activities are discrepant with expectations provides a promising mechanism for recognizing common events (e.g., a word among a long list of other words, the supermarket on the way to work) as special in some sense. It may be that planning a future activity is equivalent to pre-processing or priming the perceptual representation of the cue and/or its context. Consequently, when that cue or context occurs subsequently in the course of an ongoing task, its processing is more fluent. Because this fluency is discrepant with expectations, it causes a double take, a singularity reaction.

How does a singularity reaction affect ProM task retrieval processing? What consequences follow when a singular event is experienced in the course of an ongoing task? Einstein and McDaniel (1996) stipulate that singular events trigger a search process, a systematic attempt to find an interpretation for what caused the singularity, but they do not elaborate on how exactly the search process might be triggered. However, potentially important clues comes from the previously described research by Mandler, Jacoby, Whittlesea, and their colleagues, the results of which revealed that discrepant events support a variety of interpretations. In the context of a recognition memory experiment, for example, discrepancy seems to give rise to a feeling of familiarity whereas in a fame judgment task, discrepancy is interpreted as fame. This flexible mapping of discrepancy to task performance raises the possibility that singular events create some sort of energy, arousal, or drive, and this energy is then channeled or invested in line with the prevailing or dominant mental set, that is, the mental set required for the ongoing task.

The notion that singularity reactions and task performance are linked in this direct manner in the context of ProM may be difficult to sustain, however, primarily because of fundamental methodological differences between ProM experiments and experiments concerned with discrepancy-attribution. In previous experiments, the discrepant events always occurred in the ongoing task, under conditions where there were no other task demands and, thus, there was no outlet for the effect(s) produced by the discrepant event other than the ongoing task. By contrast, in our episodic ProM experiments, the ProM cues are bivalent, stimuli that are potentially relevant to two simultaneously available tasks—the ongoing task in the foreground and the previously planned ProM task in the background. However, if appropriate controls are in place in an episodic ProM experiment during the retrieval phase, the subject's mental set is dominated by the ongoing task. Consequently, if a discrepant event has an energizing effect, as just suggested, we would expect this effect to be channeled into the ongoing task rather than into the ProM task.

An alternative possibility is that a discrepant event or singularity reaction functions like a "task interrupt," a term commonly used in connection with computer programming and technology. The need for an interrupt signal seems self-evident. After all, if at the time of retrieval, the subject's mental set is dominated by the ongoing task, the grasp of this mental set must be severed and the subject's attention must be disengaged from this set to make a ProM task response. Singular events may serve this specific function: They may disrupt the dominant mental set at least briefly and thereby create the opportunity for attention to be switched, and to be captured by and allocated to other signals or events.

It seems likely that the influence of singularity reactions, of task interrupt signals, varies across ProM task retrieval conditions. One important property of retrieval conditions is whether events are presented at a fast pace or a slow pace, perhaps whether responding is speed- or accuracy-delimited. Under the former condition, the subject's mind requires rapid updating, rapid shifting from event to event, such that even a brief lapse of attention might produce an error. We might describe tasks of this type as requiring a high-momentum mental set[7], and contrast them with tasks associated with low-momentum sets (i.e., where event presentation is more leisurely and where responding is not speeded). It seems likely that compared to low-momentum tasks, high-momentum tasks would be much more difficult to disrupt. Consequently, we expect that, all else being equal, episodic ProM task performance would be inversely related with the momentum required for the ongoing task. Future research will explore this expectation.

Plans must be recollected

When an event—a ProM cue—occurs in the context of an episodic ProM experiment and produces a singularity reaction, this experience sets the stage for the recollection of the associated previously formed plan. But how exactly does plan recollection come about? One possibility is that recollection occurs automatically, and does not involve a controlled, attention demanding strategic search of episodic memory. The other possibility is that, in the context of an episodic ProM experiment, a singularity reac-

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[7] In physics, the momentum of an object—defined by its mass and speed—describes the capacity of the object to overcome resistance, or its tendency to keep moving in the same direction. This same construct seems useful for characterizing mental sets; it may help us understand why disrupting and shifting away from mental sets can be either easy or difficult.

tion triggers an attention demanding directed search process. The difference between these alternative possibilities is important, in part, because it may delimit the boundary between pro- and retrospective memory, or between the prospective and retrospective component of ProM task performance (see p. 310). If a singularity reaction triggers, directly or indirectly, an attention-demanding directed search of episodic memory, it would be critical to determine whether, or in what manner, this search is similar to the type of search that is engaged for explicit episodic RetM tasks. If ProM and RetM involve the exact same type of search process, it would seem that the retrospective component of ProM task performance is not unique to episodic ProM, consistent with claims made by several authors (e.g., Dobbs & Rule, 1987; Graf & Uttl, 2001; Uttl et al., 2001; Graf et al., 2002).

It is widely assumed among prospective memory researchers that memory searching and retrieval are attention-demanding processes. This assumption is anchored in and frequently justified by appeals to Craik's (1986) resource model of memory. Craik proposed that all memory tests can be arranged on a continuum according to the demands they make on attentional resources, and he suggested that retrieval for prospective memory tests is the most resource demanding. Additional support for the assumption that episodic ProM plan retrieval is resource demanding comes from Einstein and McDaniel's (1996) model, more specifically, from the claim that singularity reactions trigger an interpretive process that is, in their view, an attention-demanding directed search of episodic memory.

The notion that at least one part of episodic ProM task retrieval is attention demanding has inspired a large number of investigations that focused on the attention demands of the ongoing task (Einstein et al., 1992; Graf, 2004; Graf et al., 2002; Jacova, 2003; Marsh, Hancock, & Hicks, 2002). To illustrate, in one of our experiments, we used a display similar to that shown in Figure 1. The episodic ProM task was to press a designated key on the computer keyboard whenever a specified picture was displayed in the periphery of the display. More important, the ongoing task required either making simple reactions—to press a key whenever there was any change in the cards displayed in the center of the screen, or to make simple decisions—to press one key in response to cards containing the letter A and another key in response to cards with a B. We assumed that the latter ongoing task would be more resource demanding, and predicted that it would support a lower level of episodic ProM task performance.

The results, shown in Figure 2, are consistent with this prediction, as well as being consistent with the more general assumption that episodic ProM task retrieval is attention demanding. However, this conclusion conflicts with a substantial body of other evidence which suggests that

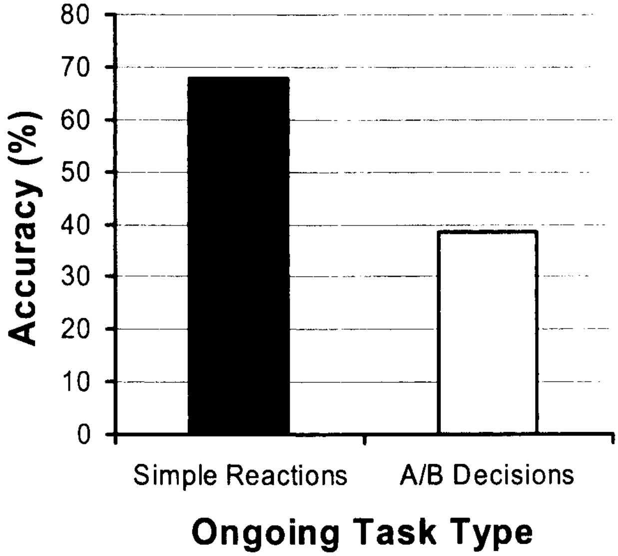

Fig. 2. The higher level of episodic ProM task performance under conditions where the ongoing task required making simple reactions as opposed to making A/B decisions.

retrieval in episodic ProM tasks is not limited by the availability of processing resources (Henry et al., 2004; McDaniel & Einstein, 2000; Otani, Landau, Libkuman, St. Louis, Kazen. & Throne, 1997).

Research on age-related changes in episodic ProM task performance also has often been mined for evidence that at least one part of episodic ProM task retrieval is attention demanding. It is widely assumed that aging is accompanied by a decline in the general or attention resources available for processing information (Hasher & Zacks, 1984; Park, 1999). Thus, consistent with the assumption of Craik's (1986) resource model, we would expect a stronger link between the availability of attention resources and performance on ProM tasks than RetM tasks. Although some evidence supports this prediction (see Uttl, this volume), the evidence is far from consistent (see Henry et al., 2004). In one of our studies (Uttl et al., 2001), we computed factor scores corresponding to episodic ProM task performance, explicit episodic RetM task performance, and attention resources. The results showed a moderate correlation between the attention resource factors and the episodic ProM task factor (.36), compared to a stronger correlation between the attention and RetM factor (.51). Moreover, a number of studies have failed to show age-related changes in event-based episodic ProM tasks (reviewed in Brandimonte, Einstein, & McDaniel, 1996; Henry et al., 2004)[8].

This combination of findings provides little support for the assumption that substantial attentional resources are required for the recollection of previously formed plans. More likely, the existing collage of results signals the desperate need for alternative theoretical accounts, perhaps inspired by recent work on explicit episodic RetM task performance. A number of recent studies in this area have explored the relative resource demands of episodic RetM task encoding and retrieval phase processing, with the results consistently showing that encoding phase processing makes larger demands on resources than does retrieval phase processing (Anderson, Craik, & Naveh-Benjamin, 1998; Craik, Govoni, & Naveh-Benjamin, 1996; Fernandes & Moscovitch, 2000). We have made the same observation (Graf, 1999; Graf & Uttl, 1998; Uttl & Graf, 1998), showing that encoding accounts for about 75% of age-related changes in episodic RetM performance, with retrieval accounting for the remaining 25%.

In a number of recent papers, Moscovitch (1992, 1994; Fernandes & Moscovitch, 2000) has argued that explicit episodic memory retrieval occurs automatically. By his view, any cue that is consciously perceived or apprehended obligatorily interacts with its associated memory trace, according to a process Tulving has described as ecphory (Tulving, 1983). Moscovitch maintains that ecphory produces a product, a response, which is delivered automatically to consciousness.

The idea that ProM plan retrieval occurs automatically may be difficult to accept, first, because the alternative—the notion that memory retrieval is attention demanding—is deeply entrenched in the prospective memory literature, and second, because accepting an automatic retrieval account would seem to leave a large body of existing results orphaned, without interpretation. However, the latter consequence does not follow. As outlined in the preceding section, ongoing tasks can be described as varying in their pacing, in the momentum of the mental sets that are required for performing them. It may be that the momentum of a task is correlated with its resource demands. What is more important, however, is that according to the view outlined in this chapter, resources are required or engaged not for the context appropriate recollection of previously formed plans, but rather for interrupting an ongoing task, for disengaging from it, and for switching to and supporting an alternative conscious content.

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[8] However, the failure to find age effects in some experiments concerned with event-based episodic ProM must be interpreted cautiously in light of the important methodological and statistical problems identified by Uttl (this volume).

This basic assumption is broadly consistent with evidence on the attentional costs of task switching (Monsell, 1996; Rogers & Monsell, 1995; Woodward, Meier, Tipper, & Graf, 2003). In addition, the finding that ,under some conditions, aging is associated with declines in ProM task performance does not require an appeal to the resource demands of memory retrieval; this is consistent with age-related changes in the tendency to perseverate, to be slower to disengage, switch, and reengage in task switching paradigms (Lewine, 2002; Monsell, 2003; Verhaeghen & Cerella, 2002).

Singular experiences functions as task interrupts

In a number of recent experiments, we explored how the experience of a singular event might affect performance on an episodic ProM task (Gao & Graf, 2005; Graf & Gao, 2004). The basic method for these experiments was the same as that used by Savchuck et al. (2004). The assigned ProM task was to press a designated key on the computer keyboard if a ProM cue was seen, with the cues displayed in the course of a lexical decision task. To manipulate the fluency of processing the ProM cue words, we primed half of them and displayed them according to the method illustrated in Figure 3. The prime was always an identity prime—the same word, displayed in the same format, as the ProM cue. Primes were displayed for 40 ms only, in light of previous research showing that this display duration produces the optimum level of unconscious influences on subsequent perceptual processing (Meier, Morger, & Graf, 2003).

One major effect due to this type of priming manipulation on episodic ProM task performance is highlighted by the results displayed in Figure 4. The right panel shows ProM task performance accuracy; the left panel shows the speed of making ProM task responses. The depicted means show a clear influence of the priming manipulation on ProM task speed, but not on performance accuracy.

We have replicated and extended this pattern of results (Gao & Graf, 2005). More importantly, in a parallel line of studies, we have demonstrated that the same type of ProM cue priming manipulation will affect task performance accuracy but not speed. For one of the latter studies, subjects were presented with word anagrams (e.g., pesed, rogund) and the ongoing task was to solve each anagram. The results, summarized in Figure 5, revealed that subjects were more likely to make the appropriate ProM task responses when presented with primed cues than when presented with unprimed cues (right panel). However, the cue priming manipulation had no effect on ProM task performance speed (left panel).

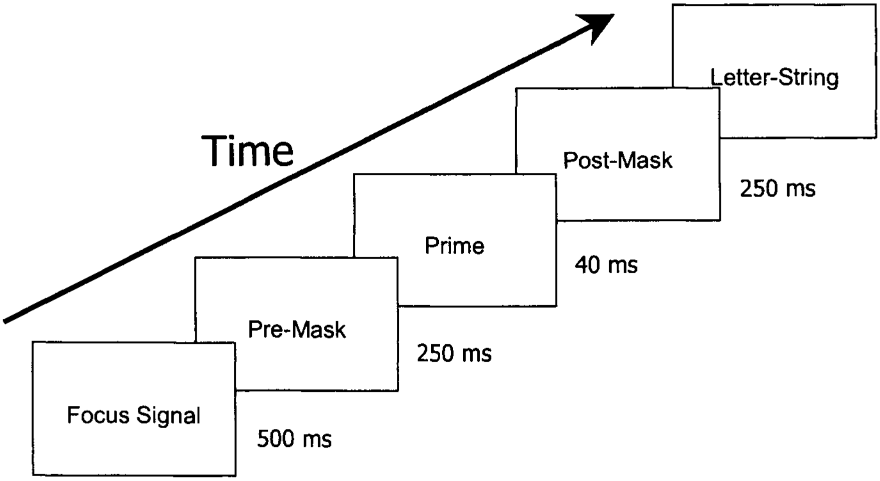

Fig. 3. The sequence of screen events that occurred on each trial. Each trial commenced with the display of a focusing signal, a star in the center of the screen. For the critical trials, the prime was always the same word, displayed in the same font and size, as the ProM cue. The ongoing task required subjects to make a word/non-word decision about each displayed letter string.

These findings are consistent with the notion that successful ProM task performance involves tracking and responding to the singularity of events that occur in the course of an ongoing activity. As outlined earlier in this chapter, we assume that in the context of a typical ProM experiment, events are perceived as singular because planning a future activity or being assigned a to-be-performed task in the laboratory serves to pre-process or prime the memory representation of the cues and/or their context. In the foregoing experiments, we "tricked" the singularity-tracking mechanism by preceding some of the ProM cues with unconscious primes. We assume that these primes increased the fluency of processing of the subsequently displayed cues such that, because subjects were not aware of the primes, the facilitated processing of the primed ProM cues was experienced as unexpectedly, oddly fluent.

The finding that unconsciously primed cues facilitated the speed but not the accuracy of ProM task performance in one experiment, whereas they benefited performance accuracy but not speed in the other experiment, underscores the complex link between detecting the singularity of an ongoing event and successful ProM task performance. As discussed earlier in this chapter, if we assume that singular or discrepant events serve to arouse or

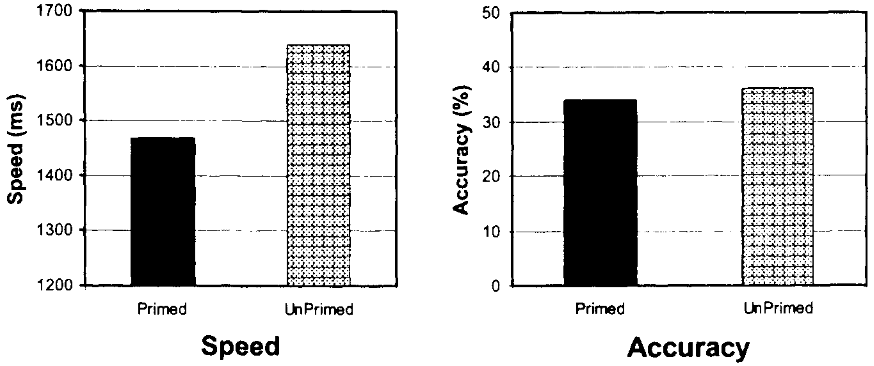

Fig. 4. Episodic ProM task performance speed (left panel) and accuracy (right panel) on cues that were either primed or not primed. The ongoing task required subjects to make lexical decisions. Statistical analysis showed no influence due to the priming manipulation on performance accuracy, but a significant effect on performance speed.

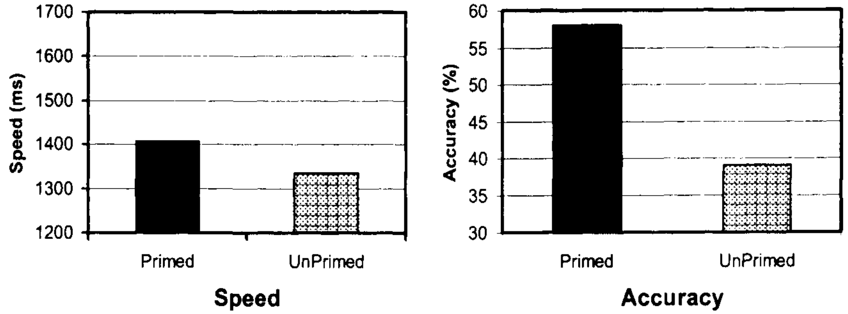

Fig. 5. Episodic ProM task performance speed (left panel) and accuracy (right panel) on cues that were either primed or not primed. The ongoing task required subjects to solve word anagrams. Statistical analyses showed a significant difference due to the priming manipulation on performance accuracy, but not on performance speed.

energize the cognitive system, and that this energy is invested in line with the dominant mental set (see p. 317), then our primed cues should have facilitated lexical decision task performance in our first experiment and anagram solution performance in our second experiment. Although not reported or discussed in this chapter, the unconscious primes did have these expected effects in our experiments (Gao & Graf, 2005). But more importantly, the priming manipulations also affected ProM task performance (see Figures 4 and 5), and these latter effects cannot be explained by appealing to an arousal mechanism.

Our results support the view that singularity reactions function as task interrupts (see p. 318), but a few additional assumptions are required to explain the specific effects depicted in Figures 4 and 5. First, we assume that our unconscious primes influenced the size of the singularity reaction produced by a cue. Second, consistent with research on repetition priming (Graf & Masson, 1993), we assume that the primes speeded up the retrieval of previously formed plans. Finally, we assume that, under dual task conditions, the behavioral responses made by subjects are determined competitively by a race between the response option triggered by the ongoing task and that elicited by the background task.

The finding in Figure 4 that unconscious primes only affected the speed of ProM plan retrieval seems at odds with the foregoing assumptions. Alternatively, it is possible that the unconscious primes had both of their normal consequences, but that the predicted effect on the experienced singularity of the ProM cues was covered up or overcome by the demands or press of the ongoing task. As defined earlier in this chapter, lexical decision making is a task that involves a high-momentum set. It is possible that a much stronger prime manipulation would be required to affect the size of singularity reactions that might be experienced under these conditions. By contrast, under the low-momentum conditions of the latter experiment, where performance was not speed-limited, we believe that the unconscious primes exerted both of their assumed influences. But because there was no premium on the speed of performance, subjects took their time to make the ProM response and thus the results showed an effect only on ProM task accuracy.

Although this interpretation of the results depicted in Figures 4 and 5 is speculative and perhaps premature, it is promising and thus merits further investigation. More importantly, by showing that unconscious primes have different effects on ProM task performance under different retrieval conditions, the results underscore two key points. First, it is necessary to distinguish between detecting the singularity of ProM cues and retrieving previously formed plans. Second, the results strengthen the claim that singular events function as task interrupts. By so doing, the results from the present studies link research on episodic ProM tasks with prior work on task switching (Rogers & Monsell, 1995) and on age-related changes in task switching performance (Monsell, 2003; Verhaeghen & Cerella, 2002), as well as with research on age-related changes in the tendency to persevere (Lewine, 2002).

Conclusion

"The road is long from the intention to the completion," wrote Molière. According to this chapter, it is now even longer than previously assumed. By contrast to the two-stage notice-and-search model of Einstein and McDaniel (1996), my major claim is that, for episodic ProM tasks, the context-appropriate recollection of previously formed plans involves three distinct stages: noticing cues, detecting the singularity of cues, and recollecting previously formed plans.

The attention, perception, and memory processes that are assumed to mediate each of the stages required for the successful recollection and execution of previously formed plans are already fairly well understood. However, future research will need to examine whether these processes function in the same manner under the dual-task conditions that are characteristic of the retrieval phase of episodic ProM tasks. In the chapter, I raised the need to address generalization questions of this type primarily in connection with singularity reactions.

The results from previous research suggest that an event which generates a singularity reaction creates some type of energy or arousal which in turn in invested in line with the mental set created by the ongoing task. However, investing energy in this manner would be counterproductive on episodic ProM tasks where subjects are confronted with two simultaneously available tasks, where success requires breaking away from the ongoing task and its guiding, consiousness-dominating mental set. For this reason, I postulated that, in the context of episodic ProM tasks, singularity reactions function as task interrupts: They set the stage for switching attention away from the dominant mental set, perhaps to be engaged for the conscious contemplation and execution of a previously formed plan.

I have linked the claim that ProM-cue-triggered singularity reactions function as task interrupts with two additional assumptions: first, that ongoing tasks differ in terms of the momentum or energy required for stopping or disrupting them, and second, that attention resources are required for disengaging from an ongoing task and for switching to and reengaging a new task. These assumptions are clearly speculative, although the second corresponds well with the attention-switching literature. However, these assumptions promise to yield new insights into the confusing collage of existing studies on how ongoing task demands affect episodic ProM task performance, as well as into research on age-related changes in episodic ProM task performance. Moreover, these new assumptions create an opportunity for aligning theoretical claims about the resource demands of retrieval for episodic ProM task with recent developments about retrieval for episodic RetM tasks.

The major theoretical challenge that is raised by the retrieval phase of episodic ProM tasks comes from the dynamic interaction of the processes that are engaged for the ongoing task versus those required for the ProM task. In most laboratory studies, both sets of processes are triggered by and relevant to the stimuli used as ProM cues. Consequently, it would seem that the occurrence of a ProM cue triggers a race between two sets of processes, one of which must win and thus dominate consciousness and responding. The probability that the ProM response wins this race is likely to depend on the strength of the link between cues and responses, as well as on the momentum of the mental sets that guides performance on the ongoing task.

Author Notes

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Hippocampal Complex Contribution to Retention and Retrieval of Recent and Remote Episodic and Semantic Memories: Evidence from Behavioral and Neuroimaging Studies of Healthy and Brain-Damaged People

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Summary. For over a hundred years, it has been accepted that remote memories are less vulnerable to disruption than are recent memories. The standard consolidation model posits that the hippocampus and related structures are temporary memory structures, necessary for acquisition, retention, and retrieval of all explicit (declarative) memories until they are consolidated elsewhere in the brain. We review lesion and neuroimaging evidence showing that important distinctions exist among different types of explicit memory and the structures that mediate them. We argue that retention and retrieval of detailed, vivid autobiographical memories depend on the hippocampal system no matter how long ago they were acquired. Semantic memories, on the other hand, benefit from hippocampal contribution for some time before they can be retrieved independently of the hippocampus. Even semantic memories, however, can have episodic elements associated with them which continue to depend on the hippocampus. In short, the evidence reviewed suggests strongly that the function of the hippocampus (and possibly of related limbic structures) is to help encode, retain, and retrieve *experiences*, no matter how long ago the events comprising the experience occurred. We conclude that the evidence favors a multiple trace theory (MTT) of memory over the traditional model, and we indicate what future work is needed to resolve disputes.

Key words. Consolidation, Autobiographical Memory, Episodic Memory, Semantic Memory, Hippocampus, Medial Temporal Lobes

Introduction

How memories are formed, retained, and recovered is one of the central and enduring questions in psychology and cognitive and behavioural neuroscience. Writing in 1904, Burnham identified two processes that were implicated in consolidation, the formation of durable memories: (1) a physiological or biochemical process needed for formation and storage of a memory trace or engram, and (2) a psychological process needed to assimilate the newly-acquired memory into an already existing body of knowledge, and to allow it, in turn, to influence what will be learned subsequently. Elucidating these processes remains at the heart of research on memory and consolidation, and will be the focus of this chapter. In particular, we will examine two types of memory—episodic (autobiographical) and semantic—and investigate what studies of remote memory can tell us about the neural substrates mediating them, how they may be modified with time, and what implication that knowledge has for general psychological theories of memory.

Recent work has begun to clarify the nature of the separate yet interactive roles of the hippocampal complex and the neocortex in memory storage and retrieval. The hippocampal complex, located in the medial temporal lobe (MTL), includes the hippocampal formation, the peri-rhinal and entorhinal cortex, and the parahippocampal cortex, and is linked to other structures in the limbic system (see Figures 1 & 2). Most of the work in human and non-human species has focused on anterograde memory—the acquisition, storage, and retrieval of new or recently-acquired memory. These studies have been instrumental in calling attention to the role that different areas of neocortex and sub-regions of the MTL play in explicit and implicit memory, although the precise nature of those functions is still in dispute (Burgess, Maguire, & O'Keefe, 2002; Murray & Bussey, 2001; Murray & Richmond, 2001; Squire & Zola, 1998). Studies on the role of the MTL and neocortex in retrograde or remote memory are rarer, yet such

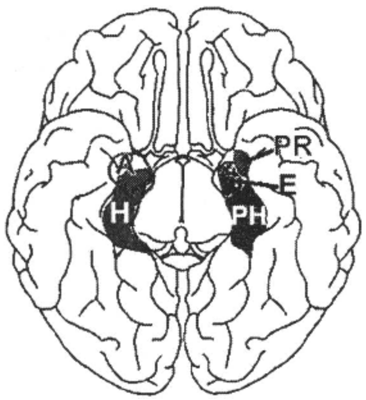


Fig. 1. Medial temporal lobe structures viewed from the underside of the brain. A: Amygdala; E: Entorhinal Cortex; H; Hippocampus; PH: parahippocampal cortex; PR: Perirhinal cortex.

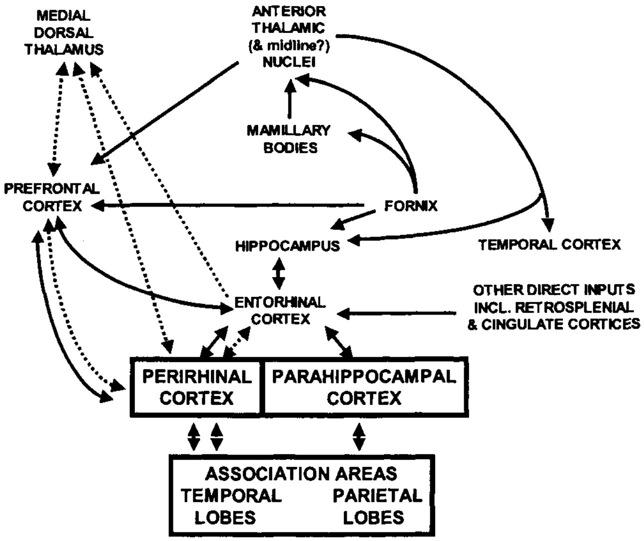


Fig. 2. The hippocampal-diencepahalic systems showing connections between medial temporal structures and diencepahlic (thalamic) nuclei and frontal lobes. Solid lines show the extended hippocampal system, presumed to mediate recollection, and dotted lines show the extended perirhinal system, presumed to mediate familiarity. (Modified from Aggleton & Brown, 1999).

studies are crucial for answering our central question: What is the role of the hippocampus and neocortex in consolidation, retention, and retrieval of memories acquired long ago?

The work reported in this chapter is a team effort. It began in 1996 while Morris Moscovitch was on sabbatical leave at the University of Arizona, where he was working with Lynn Nadel. Moscovitch was invited to present a talk on consolidation at a conference at Tel-Aviv University, and recruited Nadel as a co-author. Intending simply to update evidence favoring the standard view of memory consolidation, they reviewed the recent literature and realized that the data were much more troublesome to that view than they had anticipated. Instead of trying to fit the data to the standard model, they proposed a new one, to be described shortly (Nadel & Moscovitch, 1997). Those ideas, however, would have had little credibility, and less currency, without the evidence gathered by a large team of investigators who at first were as skeptical of our ideas as were our critics. The research efforts of this large team nurtured the ideas that were hatched in Arizona and allowed them to take flight.

A very brief history of the problem of remote memory and consolidation

Over the last few years, a number of reviews have been written on consolidation (Dudai, 2004; Kandel, 2001; Moscovitch, 2001; McGaugh, 2000) so there is no need to repeat those reviews here. The term "consolidation" was introduced by Müller and Pilzecker (1900) to describe a time-dependent process that was needed to assimilate an experience and store it permanently as a memory that was relatively immune to disruption. Although there was some sophisticated, prescient speculation about the processes involved in consolidation (Burnham, 1904), until 1950 little was known about the neural (but see Korsakoff, 1889) and biochemical substrates of memory or how they were implicated in consolidation.

The next half century saw a number of important developments but none was as momentous as Scoville and Milner's (1957) publication on the effects of excision of the anterior, medial temporal lobes (MTL) bilaterally to control intractable epilepsy in a single patient, H.M. (for an MRI reconstruction of H.M.'s lesion, see Corkin, Amaral, Gonzalez, Johnson, & Hyman, 1997). This publication was followed by a report of three additional cases with unilateral excisions with presumed damage to contralateral MTL structures (Penfield & Milner, 1958). These cases focused attention on the hippocampus and related structures in the MTL as being crucial for long-term memory. Although the surgery was effective in controlling H.M's epilepsy, one of its unanticipated consequences was that he developed a profound anterograde amnesia, while retaining normal intelligence, short-term memory, and perceptual and motor functions. The other patients suffered a similar fate. Remote memory loss was believed to be limited to about 3 years (Corkin, 1984; Milner, 1966; but see Corkin, 2002).

These observations were interpreted as showing that the medial temporal lobes and related diencepahlic structures were involved neither in processing short-term memories nor in storing remote memories. Instead, their function was to help encode and consolidate memories, and to store and retrieve those memories until consolidation was complete (Squire, 1992; Zola-Morgan & Squire, 1990). Indeed, the standard model of consolidation was based on these initial observations and has been modified little since then (Milner, Squire, & Kandel, 1998; Moscovitch, 2001).

The standard model

According to the standard model (Dudai, 2004; McGaugh, 2000; Squire & Alvarez, 1995), memory consolidation begins when information, registered initially in neocortex, is bound into a memory trace by the MTL and related structures in the diencephalon. This initial binding into a memory trace involves short-term processes. The first of them may be completed within seconds, and involves transient molecular changes at the synapse. These, in turn, can give rise to a cascade of events, lasting minutes or at most days, which entail genetic transcription and protein formation that lead to long-lasting cellular changes, including the creation of new synapses (Dudai, 2004; Kandel, 2001). These changes support the formation and maintenance of long-term memory. We refer to this process as *rapid consolidation* or *cohesion* (Moscovitch, 1995) or *synaptic consolidation* (Dudai, 2004) to contrast it with a process of *prolonged consolidation* or *system consolidation* (Dudai, 2004) which, according to the standard model, can last on the order of years or even decades.

During prolonged consolidation, it is assumed that the medial temporal lobes and related structures are needed for storage and recovery of the memory trace, but their contribution diminishes as prolonged consolidation proceeds, until the neocortex alone is capable of sustaining the permanent memory trace and mediating its retrieval (Markowitsch, 1995). Thus, the MTL and related structures are considered by the standard model to be temporary memory systems, needed to store and retrieve memories until prolonged or system consolidation is complete. The time it takes for consolidation to be complete is estimated by the temporal extent of retrograde amnesia following lesions of the MTL and diencephalon, other kinds of insults (concussions, closed head injuries, or electrical currents), or the administration of pharmacological agents which disrupt memory permanently.

The existence of rapid consolidation is not in dispute by proponents of the standard model nor by their adversaries. Much has been learned about its cellular and neurochemical (molecular) basis, which seem to be similar across species and across different memory systems in the same species (see Dudai, 2004; Kandel, 2001). We are, however, far from understanding memory at a systems level (but see Dudai, 2004; Frankland & Bontempi, in press), a problem that is inextricably tied to ideas concerning prolonged consolidation, ideas which form the crux of the debate (Squire, Cohen, & Nadel, 1984) and the focus of this chapter.

Prolonged consolidation and memory systems

By the 1960s, the outlines of the central debate concerning the validity of the standard model of consolidation were clearly crystallized in work with amnesic patients, reflecting the assumption that it was damage in the MTL and diencephalon that was primarily responsible for the amnesia (Warrington & Sanders, 1971; Warrington & Weiskrantz, 1970). Although the debate has many facets, in this chapter, the focus is only on one of them: What is the extent and duration of retrograde amnesia and, by implication, of consolidation, and how are they affected by lesion location and memory type?

Types of memory

One of the major contributions of memory researchers in the latter part of the 20th century is the idea that memory is not unitary but consists of various types, each influenced by different variables, governed by different principles, possibly concerned with different materials, and each mediated by different neural structures and mechanisms that form distinguishable, and dissociable, systems (see Cermak, 1982; Moscovitch, 1992, 2001; Tulving & Craik, 2000; Schacter & Tulving, 1994). Although many different types of memory have been identified, including the broad classes of explicit (conscious) and implicit (unconscious) memory (Graf & Schacter, 1985; Moscovitch, Vriezen, & Goshen-Gottstein, 1993), the two most relevant to the debate are episodic and semantic memory (Tulving, 1972, 1983), both of which can be considered explicit (Moscovitch, 1982, 1984; Schacter, 1987) or declarative (Squire, 1992).

Episodic memory refers to memory for particular, autobiographical episodes that have a distinct spatio-temporal context and involves a detailed re-experiencing of the initial event. Tulving (1985) refers to this re-experience as "mental time travel" which relies on autonoetic consciousness (consciousness with the self in it). In studies of anterograde memory, episodic memory is assessed by tests of *recollection*, which refers to representation of past experiences and includes not only the content of those experiences but also their spatial-temporal context. Building on Tulving's distinction, Moscovitch (1995, 2000) emphasized that episodic memory also includes the *conscious experience* accompanying the episode. Put succinctly, episodic memory refers to memory of the *experience* of the event, of which conscious awareness is a part.

Semantic memory, on the other hand, is knowledge that lacks a spatio-temporal context, such as knowledge of vocabulary and facts about the world (history, geography, people). Semantic memory even includes knowledge about ourselves (where we were born, where we lived, who our friends were, what schools we attended, what jobs we held), what some have called *personal semantics* (Cermak & O'Connor, 1983; Kopelman, Wilson, & Baddeley, 1989) to distinguish this aspect of memory from that for autobiographical episodes.

There is another type of memory that figures prominently in research, and that has elements of both semantic and episodic memory, and that is *familiarity* with a past event. Familiarity refers to recognition that an event had occurred to one personally but without the information needed to place it in an autobiographical context. For example, familiarity is the kind of memory that occurs when you encounter a person whom you recognize as familiar but you cannot place the individual or the encounter in a particular time or place. This memory shares attributes both with episodic memory, in that it is memory for a particular bit of information linked to an episode, and with semantic memory, in that it lacks a defining spatio-temporal context. As we shall see, these distinctions, which have gained in importance in studies of anterograde memory over the last decade, also have come to play an important role in studies of retrograde or remote memory.

Although different types of tests are used to assess episodic and semantic memory, proponents of the standard model consider them to be similar with respect to consolidation. According to these investigators, damage to the medial temporal lobes and diencephalon leads to a graded, temporally-limited retrograde amnesia for all types of declarative memory. Memories acquired most recently are most severely affected, with more remote memories being retained normally, having been fully consolidated before the neurological insult (see Bayley, Hopkins, & Squire, 2003; Manns, Hopkins, & Squire, 2003; Squire & Alvarez, 1995, Reed & Squire, 1998; Rempel-Clower, Zola, Squire, & Amaral, 1996).).

Critique of the Standard Model

The standard model of consolidation had been challenged by Warrington and her colleagues who showed that retrograde amnesia can be severe and of long duration following medial temporal lesions. This finding led them to favor the view that amnesia results from a deficit in retrieval rather in consolidation (Warrington, 1996; Warrington & Sanders, 1970; Warrington & McCarthy, 1988). Kinsbourne and Wood (1975), on the basis of evidence they collected using Crovitz and Schiffman's (1974) cuing technique, argued that amnesia is a deficit only of episodic memory, and affects recent and remote memory equally. Although few endorsed their ideas at that time, Nadel and Moscovitch's (1997; Nadel et al., 2000) recent reviews sided more with their position than with the standard model. Nadel and Moscovitch noted a number of problems with the standard model, both with respect to the types of memories that are affected and with the duration and extent of retrograde amnesia.

Retrograde amnesia varied with memory type, decreasing in severity and extent from the autobiographical to the semantic. In people with large MTL (or diencepahlic) lesions, retrograde amnesia for details of autobiographical events can extend for decades, far longer than it would be biologically plausible for even prolonged consolidation to be completed, or even a lifetime. Retrograde amnesia for public events and personalities which, as we shall see is contaminated by autobiographical information, is less extensive and often is temporally graded; this is truer still of semantic memory that pertains to vocabulary, to facts about the world, and to personal semantics (see Fujii, Moscovitch, & Nadel, 2000; Kapur, 1999, Kopelman & Kapur, 2001; for extensive reviews of retrograde amnesia).

The relevance of the neuroanatomical components of the medial temporal lobes and related structures

It is a truism (or principle) in cognitive neuroscience that distinct psychological functions are associated with distinct neural substrates or processes.

It is not surprising, therefore, that the new developments in our psychological understanding of memory were accompanied by comparable developments in our appreciation of the neuroanatomy of memory. Nadel and Moscovitch (1997, 1998; Nadel et al., 2000, 2003) noted that lesion size and location play a role in determining the nature, severity, and extent of retrograde amnesia. The initial studies on retrograde amnesia implicated the MTL and diencephalon. As we noted, however, these areas themselves are comprised of a number of separate, but related, structures (see Figure 1).

Following Scoville and Milner's (1957) report, attention shifted quickly from the medial temporal lobes to the hippocampal formation, and then to the hippocampus itself. More recently, however, investigators have begun to appreciate the importance of the other structures, the different functions each serves, as well as their relation to each other and to corresponding regions in the diencephalon (see Aggleton & Brown, 1999).

One system, consisting of the hippocampus and its connections to the mammillary bodies and anterior thalamic nuclei, is presumed to mediate recollection which relies on relational information, including the temporal-spatial context of the memory (see Figure 2). Damage to this system causes deficits in spatial memory and in memory for complex relational information that typifies memory for autobiographical episodes, but spares recognition based only on familiarity (Aggleton et al., 2000; Holdstock et al., 2002a; Mayes et al., 2002, 2004; D. Moscovitch & McAndrews, 2002; Yonelinas, 2002; Yonelinas et al., 2002). The other system, consisting of the peri-rhinal cortex and its connections to the dorsomedial nucleus of the thalamus, is necessary for item recognition based on familiarity judgments which do not require access to spatial-temporal context (see Figure 2). Damage to this system will impair recognition even of single items (Aggleton et al., 2000). The parahippocampal cortex seems to be necessary for forming memories of places (Epstein & Kanwisher, 1998; Epstein, Harris, Stanley, & Kanwisher, 1999; Epstein, Graham, & Downing, 2003) or of associating objects with particular locations (Owen, Milner, Petrides, & Evans, 1996a,b), and may provide the allocentric, spatial framework for recollection (Burgess, Becker, King, & O'Keefe, 2001; Burgess, Maguire, & O'Keefe, 2002; Nadel & Moscovitch, 1997; O'Keefe & Nadel, 1978; Rosenbaum et al., 2000).

Based on the functional and neuroanatomical evidence which they reviewed, Nadel and Moscovitch (1997, 1998; Moscovitch & Nadel, 1998; Nadel et al., 2000) concluded, contrary to the traditional consolidation model, that the function of the medial temporal system is not temporally-limited but that it is needed to represent even old memories in rich detail, be they autobiographical or spatial, for as long as the memories exist.

Nadel, Moscovitch and their colleagues (Fujii et al., 2000; Nadel & Moscovitch, 1997; Nadel et al., 2000, 2003; Rosenbaum et al., 2000) noted that the extent and severity of retrograde amnesia depended on the size of the lesion—the larger the lesion, the greater the loss—with episodic, autobiographical memory being the most severely affected. They proposed that the entire medial temporal region, what has been called the hippocampal complex after its most prominent structure, is needed for storage and retrieval of episodic memories, however remote.

Given the multifaceted nature of autobiographical episodes, Nadel and Moscovitch (1997, 1998) suggested that each of the various regions of the medial temporal lobe may contribute its own information to the complete, detailed memory of an event, although they left the precise formulation vague. As we have learned more about the separate functions of medial temporal regions, it may make sense to consider the possibility that each of them is involved in retention and retrieval of those aspects of an event which they specifically process. *Thus, for remote memory, as for anterograde memory, recollection of autobiographical episodes will always depend on the hippocampus.* Recognition based on familiarity can survive hippocampal damage, but not damage to peri-rhinal cortex, whereas recognition of aspects of places will be impaired following parahippocampal lesions.

Neocortical structures, on the other hand, are sufficient to form domain-specific and semantic representations based on regularities extracted from repeated experiences with words, objects, people, and environments (Rosenbaum et al., in press). This applies even to autobiographical episodes that one recollects repeatedly, thereby creating a gist of each episode which lacks the details that makes rich re-experiencing possible. The MTL system may aid in the initial formation of these neocortical representations (Nadel & Moscovitch, 1997), but, once formed, they can exist on their own. We return to this point later when we discuss semantic memory.

Multiple Trace Theory

Nadel and Moscovitch (1997) referred to their model as the *Multiple Trace Theory (MTT)* of memory (see Estes, 1964, for an earlier related psychological model). According to MTT, the hippocampal complex (and possibly diencephlon) rapidly and obligatorily encodes all information that is attended (consciously apprehended), and binds the neocortical (and other) neurons that represent that experience into a memory trace. This information is sparsely encoded in a distributed network of hippocampal complex neurons which act as pointers to, or index, the neurons that represent the attended information (Teyler & DiScenna, 1986). A memory trace of an episode, therefore, consists of a bound ensemble of neocortical and hippocampal/medial temporal lobe (and possibly diencephalic) neurons which represent a memory of the consciously-experienced event. Formation and consolidation of these traces, or cohesion (Moscovitch, 1995), is relatively rapid, lasting on the order of seconds or at most days (rapid consolidation).

According to MTT, and in contrast to the standard consolidation model, there is no prolonged consolidation process that slowly strengthens the neocortical component of the memory trace so that with time it becomes independent of the hippocampal complex. Instead, each time an old memory is retrieved, a new hippocampally-mediated trace is created so that old memories are represented by more or stronger traces than are new ones, and therefore old memories are less susceptible to disruption from brain damage than are more recent ones. Because the memory trace for autobiographical episodes is distributed in the hippocampal complex, the extent and severity of retrograde amnesia, and perhaps the slope of the gradient, are related to the amount and location of damage to the extended hippocampal complex. This idea fits reasonably well with the available evidence (see Fujii et al., 2000; Nadel & Moscovitch, 2001).

Whereas each autobiographical memory trace is unique, the creation of multiple, related traces facilitates the extraction of the neocortically-mediated information which is common among them, and which is shared with other episodes. This information is then integrated with pre-existing knowledge to form semantic memories that can exist independently of the hippocampal complex. Thus, facts about the world, people, public and even personal events (their gist, not contextually-rich information) that are acquired in the context of a specific episode can be separated from the episode and ultimately stored independently of it, although in some cases episodic information may be retained in parallel. This process of some memories becoming increasingly semantic may give an impression of prolonged consolidation, as we shall see later.

Tests of MTT and the standard model: Autobiographical memory

Recent research developments show, however, that autobiographical memory itself consists of multiple components, each likely mediated by different brain mechanisms (see Conway & Playdell-Pierce, 2000; Conway & Fthenaki, 2000; Conway et al., 2003; Ogden, 1993; Rubin & Greenberg, 1998; Greenberg & Rubin, 2003, and references therein). Autobiographical memory appears to be organized hierarchically with life-time periods (e.g., high school, university, first jobs) at the top of the hierarchy, general event memories in the middle (going on vacation, visiting friends, family dinners), and unique, specific events which have detailed perceptual information at the bottom. Associated with each of these is semantic knowledge related to the event (e.g., with regard to vacation, general knowledge about the location being visited is incorporated into the memory). Finally, retrieval occurs within the "working self" (Conway & Playdell-Pierce, 2000; Conway & Fthenaki, 2000), a type of working memory that contains current conceptions of one's self and one's long-term and immediate goals that influence, direct, and monitor retrieval.

The aspect of autobiographical memory most relevant for our concerns is unique, specific events because it is these which correspond to autobiographical recollection, the feeling of traveling back in time and re-experiencing the event mentally. The greatest divergence between the two models concerns this aspect: MTT predicts that such event-specific memories always depend on the hippocampus, no matter how old they are, whereas the standard model predicts that only more recent memories are hippocampally-dependent.

To be sure, recalling event-specific information may also implicate other components of autobiographical memory and the structures that mediate them. For example, in recalling a specific event that occurred at one's home, knowledge of the house, the items in it, their location, and so on, forms the background against which the event-specific memory occurs. One of the tests that we have devised (Levine, Svoboda, Hay, Winocur, & Moscovitch, 2002), *The Autobiographical Interview,* distinguishes between those elements that are specific to the event (internal details) and those which are shared with other events or are derived from general knowledge (external details).

Another way of distinguishing the experiential aspects of the event from those which are more generic is simply to count the number of details which an event conjures in memory (Moscovitch, Yaschyshyn, Ziegler, & Nadel, 1999) or rate the memory along dimensions such as vividness (Addis, Moscovitch, Crawley, & McAndrews, 2004a; Gilboa, Winocur, Grady, Hevenor, & Moscovitch, 2004). According to MTT, only those autobiographical memories high in internal details and vividness depend on the hippocampus, no matter how old they are. It remains to be seen whether generic memories, or other aspects of specific event memories—such as their semantic component or familiarity—also continue to depend on the hippocampus (see Addis, McIntosh, Moscovitch, Crawley, &

McAndrews, 2004b; Graham, Lee, Brett, & Patterson, 2003, for relevant neuroimaging studies).

Although this chapter emphasizes the medial temporal lobe, and in particular the hippocampus, one should not lose sight of the fact that retrieving autobiographical memories requires the interaction of the medial temporal lobes with other neocortical and subcortical structures. We are mindful of the contribution of these other structures, but will refer to them only occasionally here (for more information, see Addis et al., 2004a, b; Conway & Pleydell-Pierce, 2000; Conway & Fthenaki, 2000; Gilboa, 2004; Gilboa et al., 2004; Graham et al., 2003; Maguire, Vargha-Khadem, & Mishkin, 2001; Maguire & Frith, 2003; Murre, Graham, & Hodges, 2001; Piefke, Weiss, Zilles, Markowitsch, & Fink, 2003; Ryan et al., 2001).

The studies we present in the following sections are our own, and are not meant to provide a comprehensive review of the area. We will refer to other studies as needed, and will try to note discrepancies with other studies when they bear on the main questions being addressed.

Neuroimaging

According to the standard model, activation of the hippocampal complex should be greater for recent than for remote memories, whereas the reverse should be the case for the neocortex. MTT, however, predicts that the hippocampal complex will be activated equally by retrieval of recent and remote autobiographical memories, as long as they are vivid or detailed. Using cues (Ryan et al., 2001) or statements (Maguire, 2001; Maguire et al., 2001, 2003) derived from pre-scan interviews, and event-related functional magnetic resonance imaging (efMRI) designs, investigators have found greater bilateral hippocampal activation associated with re-experiencing of particular autobiographical events, or mostly left-sided activation while making recognition judgments about statements referring to autobiographical events in comparison to control conditions that included general personal events or public events. Most importantly, hippocampal activation was equivalent for recent and remote memories, thereby favoring MTT over the standard model. Piolino, Giffard-Quillon, Desgranges, Che'telat, Baron, & Eustache (2004) reported similar findings and conclusions using positron emission tomography (PET).

A possible confound in these studies concerns item selection. Because participants selected the memories used in the experiment, either right before scanning or even weeks earlier, it is difficult to know whether they retrieved truly remote memories in the scanner, or only refreshed those memories which were recovered more recently during the selection process. Ryan et al. (2001) controlled for this possible confound by scanning three additional participants whose autobiographical events were selected by a close relative or friend, and Maguire et al.(2001) controlled for it by testing the developmental hippocampal amnesic, Jon, for the few events he could recollect from his remote past, even though he had no memory for the pre-scan interview. In both cases, greater hippocampal activation—that did not vary with time—was found for autobiographical than for other events.

Another possible confound is that hippocampal activation accompanies *re-encoding* of memories as they are retrieved in the scanner, rather than being associated with the initial retrieval itself. Sensitive to this criticism, Gilboa et al. (2004) addressed it in their study. They had a person close to the participant select family photos which the participant had not viewed recently and which were shown only in the scanner. The photos were from five time periods dating from early childhood (at least 20 years ago) to the last six months. To control for the effect of re-encoding, the participant also was presented with photos from a stranger's family album which were matched as much as possible in content to the participant's own photos.

On viewing "self" photos in the scanner, the participant had to re-experience the depicted event in as much detail as possible; in viewing the "other" photo, the participant had to imagine in equivalent detail a scenario concerning the event depicted in the unfamiliar photo. If re-encoding were a factor, no difference in hippocampal activation should be observed between the "self" and "other" conditions. Gilboa et al. (2004) found that activation was greater for old, "self" memories than for novel, imagined "other" material in a number of regions, including the left hippocampal complex (see also Addis et al., 2004a; Maguire et al., 2001), thereby arguing against the re-encoding interpretation.

Of equal interest was the finding, consistent with MTT but not with the standard model, that left hippocampal activation was related not to the age of the memory, but rather to its richness, as determined by post-scan vividness ratings for all of the memories and description for a subset of them from each time period (see Figure 3). Because Gilboa et al. (2004) found that, on average, recent memories are more vivid and detailed than remote memories, it is likely that these variables, rather than age, account for the temporally-graded hippocampal activation reported in other studies (Eustache et al., 2003; Maguire & Frith, 2003; Niki & Luo, 2002; Piefke et al., 2003).

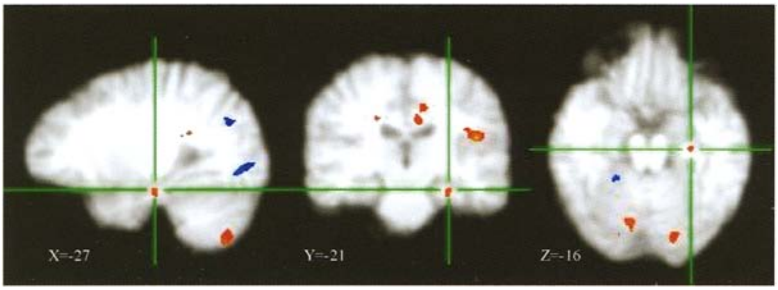


Fig. 3. Activation from vividly (red) versus non-vividly (blue) recalled events. The cross hairs on the images are centered at activations within the spherical search regions of the hippocampus which have the following Talairach and Tournoux (1988) co-ordinates: Reading from left to right, $x = -27$, $y = -21$, $z = -16$). Radiological co-ordinates are used so that left-right is reversed. (From Gilboa et al., 2004).

This interpretation was confirmed in a parallel efMRI study by Addis et al. (2004b) designed to determine whether recency or recollective qualities, such as detail, emotionality, and personal significance, modulate hippocampal activity during retrieval of autobiographical memories of unique or repeated events. During scanning, participants retrieved temporally specific autobiographical memories and general, repeated autobiographical memories, and rated each for level of detail, emotionality, or personal significance. Addis et al. found that medial temporal activation during the retrieval of either specific or repeated autobiographical memories varied with the level of detail, personal significance, and emotionality. Recency independently modulated hippocampal activity, but its effects were reduced or eliminated when the other factors were included as a covariates. Conversely, robust modulation of hippocampal activation was observed for the three qualities even when recency was included as a covariate. Consistent with MTT, the results suggest that recollective qualities, not recency, are the important predictors of hippocampal engagement during retrieval of autobiographical memories.

Gilboa et al. (2004) also found that foci of activation in the hippocampus were distributed differently for recent and remote memories, with the former clustered in the anterior region of the hippocampus and the latter distributed along its rostro-caudal axis (see Figure 4). It is not yet clear why this pattern should occur. If each retrieval leads to the formation of new traces within the MTL, as MTT predicts, then remote memories should be more widely distributed than recent memories in MTL, and may survive minimal damage to the MTL.

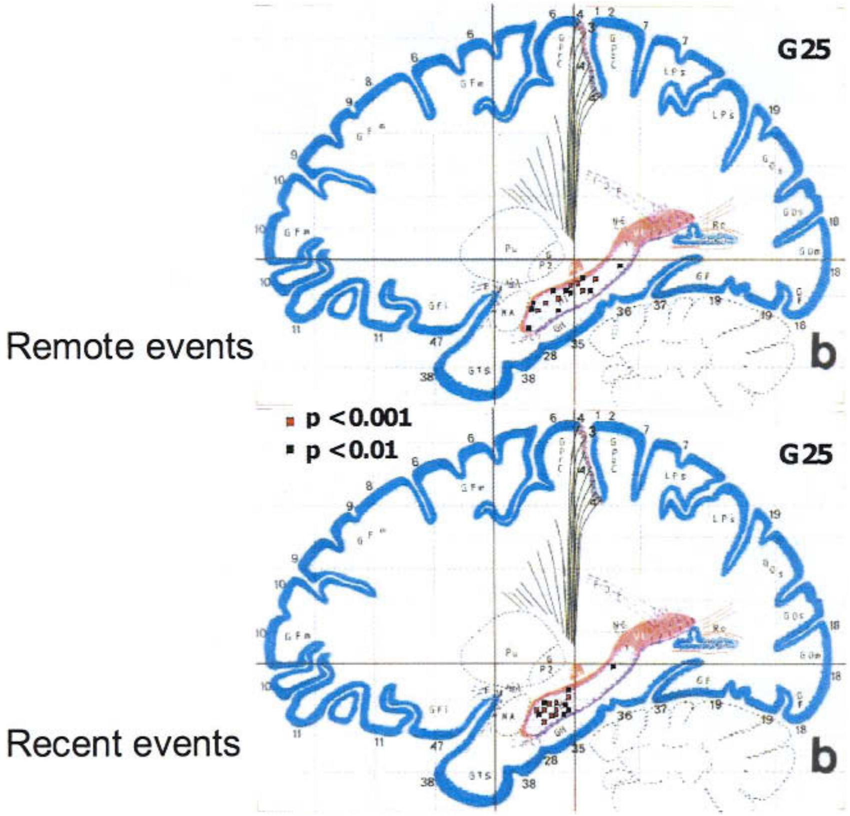


Fig. 4. Schematic renderings of remote and recent activations. Each point corresponds to a statistically significant activation from within the left hippocampus in either remote (top; $n = 18$) or recent (bottom; $n = 16$) conditions. Red and black squares represent activations at a significance level of $P < 0.001$ and $P < 0.01$ uncorrected, respectively. Activations are shown on a single sagittal plane taken from the Talairach and Tournoux (1988) atlas (25 mm lateral to the midline). Overlapping activations were offset slightly in the recent condition. Differences in the lateral displacement of the activations from the midline (along the x-axis of the Talairach atlas) are not represented in the figure. The lateral and vertical dimensions did not show any obvious systematic variability and therefore are not considered as a part of the overall pattern of interest. (From Gilboa et al., 2004).

Other possible interpretations of this pattern of activation are that remote memories, particularly those dating to childhood and adolescence, may be encoded differently from more recent, adult memories, or that recent memories may retain their emotional strength more than remote ones. With respect to the latter possibility, Dolcos et al. (2002) reported that emotional memories activated the anterior hippocampus more than nonemotional ones, although in their study emotionality interacted with recollection, and all their memories were recent by our standards.

Summary. The neuroimaging studies that we have conducted support MTT's predictions that the hippocampal complex is needed for retention and retrieval of rich autobiographical memories no matter how old those memories are (see also Conway et al., 1999, and the review by Maguire, 2001). Our findings also help explain why recent autobiographical memories sometimes lead to greater hippocampal activation than do remote memories: Recent memories tend to be more vivid and experientially richer than remote ones. Once these qualities of memory are controlled or factored out, recency no longer is a modulating influence on hippocampal activation. The foci of activation for recent and remote memories were distributed differently in the hippocampus, the former clustering in the anterior portion, and the latter distributed along the rostrocaudal axis. Together, these studies indicate that it is the richness of the memory or the re-experience, rather than its age, that determines the extent of hippocampal involvement. This pattern is consistent with MTT, but contrary to the standard consolidation model.

Lesion studies

Despite the confirmatory evidence from neuroimaging studies, these results are fundamentally correlational: They indicate that the hippocampus is implicated in retrieving remote autobiographical memories, not that it is needed to do so (Shimamura, 2002). Only evidence from lesion studies can address that question conclusively. If the hippocampal complex is needed for retrieval of remote autobiographical memories, then damage to it should lead to remote memory deficits.

The evidence in the literature is mixed on this point. In reviewing the literature until 1998 on damage restricted to the medial temporal lobe, Fujii et al. (2000) noted that as the damage extends from the hippocampus proper to the adjacent medial temporal lobe regions, so does the extent of retrograde amnesia from a few years to a lifetime, if the entire complex is implicated. In the few cases in which damage was confined to the hippocampus proper, retrograde memory loss was limited to just a few years. Some recent studies, however, suggest that severe and extensive retrograde amnesia for autobiographical events can occur even with damage confined to the hippocampus (Cipilotti et al., 2001, and discussion in Nadel & Moscovitch, 2001). As well, H.M.'s retrograde amnesia which was reported to last only for three years (Scoville & Milner, 1957), has been extended to 11 years (Corkin, 1984), and even longer (Corkin, 2002) for his autobiographical memory.

A possible reason for the discrepancy among the studies is that the measures used to assess remote autobiographical memory were not sensitive enough to capture its richness, or to distinguish the specific, episodic component from the more generic or semantic one. Typically, autobiographical memory is scored on a three-point scale, with the maximum number of points awarded if information about the temporal-spatial context is supplied along with some details (Crovitz & Schiffman, 1974; Kopelman et al, 1989). Such a system, however, would not distinguish between a report that contains just enough information to get a maximal score and one that supplies far more details. Scoring memories according to the total number of details that are supplied, much as one would score the logical stories on Wechsler Memory Scale for anterograde memory, would provide a more accurate measure of how well remote memory is preserved. By adopting this new scoring technique, we showed a remote memory deficit for all time periods except early childhood, where it was absent not because memory in amnesic patients was good, but because memory in normal people was also impoverished (Moscovitch et al., 1999; Nadel et al., 2000).

As informative as that study was, leading to development of a new, reliable method of assessing remote memory (Levine et al., 2002), the amnesic patients who participated in it were a heterogeneous group, none of whom had damage confined to the hippocampal complex. To determine whether similar extensive memory loss could be observed in people with medial temporal lobe damage, we tested people with unilateral temporal lobe epilepsy either before or after anterior, medial temporal lobectomy (Viskontas, McAndrews, & Moscovitch, 2000). Even though we used a standard test of autobiographical memory (The AMI by Kopelman et al., 1989), we found a retrograde memory loss dating back to early childhood, with no temporal gradient, even in individuals with late onset (after age 16) seizures (See Figures 5a,b). In fact, there is a suggestion that the deficit was more severe in the late onset cases, paralleling Seidenberg et al.'s (1997) finding on anterograde memory loss. Personal semantic memory, however, was unaffected at all time periods tested (see Figure 5c).

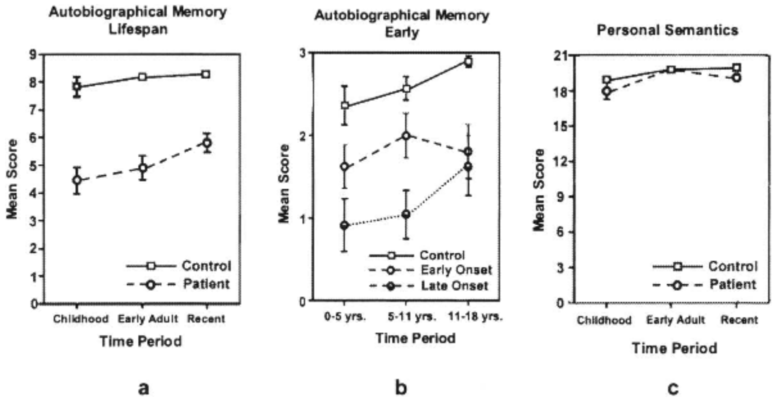


Fig. 5. Left panel: Autobiographical episodic memory performance. Mean scores on episodic components of the Autobiographical Memory Interview (AMI; Kopelman et al., 1989) for control (n=22) and patient (n=25) groups. The maximal score is 9 per time period. Vertical lines depict standard errors of the means. **Middle panel:** Autobiographical episodic memory performance during earliest time periods. Mean scores on episodic components of AMI for control (n=22), late seizure onset (n=11), and early seizure onset (n=8). Late seizure onset describes patients who reported first seizures after age 18, early seizure onset describes patients who reported first seizures before age 5. The maximum score is 3 per time period. **Right panel:** Personal semantic memory performance. Mean scores on semantic components of AMI for control (n=22) and patient (n=25) groups. The maximum score is 21 per time period. Vertical lines depict standard errors of the means. (From Viskontas et al., 2001).

These findings do not imply that remote autobiographical memories are lost; rather, they indicate that remote memories are impoverished. Even severely amnesic people may retain the gist of particular events without the rich detail that allows them to be re-experienced vividly. The convergence of amnesic and normal memory at remote time periods that sometimes is observed, and that can give the impression of a temporal gradient, likely occurs because many remote memories, even of neurologically-intact people, are impoverished, less experiential and more semantic (Cermak & O'Connor, 1984) compared to their recent memories (see Gilboa et al., 2004), and not because remote memories are preserved in amnesia.

Proponents of the standard model argue, however, that severe, and temporally extensive, retrograde amnesia is observed for autobiographical events only if the lesion encroaches on the lateral temporal cortex, not if it is confined to the medial temporal lobe. Thus, working with people with such circumscribed lesions, Bayley, Hopkins, and Squire (2003) reported that autobiographical memories of the first third of their patients' lives (dating back 20-40 years) were normal, even though they used Levine et al.'s (2002) more sensitive scoring technique. The methods used for eliciting the memories, however, were different from those used by Moscovitch et al. (1999) and Levine et al. (2002), and judging from the data, they were not as effective. Indeed, whereas the number of details, both event-specific (internal) and generic (external), produced by control subjects in Bayley et al.'s study averaged only 18 per memory, those in Levine et al.'s and Moscovitch et al.'s study averaged 100. Indeed, their controls produced far fewer details than many of our amnesics, some of whose lesions were substantially larger than the lesions of Bayley et al.'s patients.

It is very likely that the memories sampled by Bayley et al. (2003) were not what we have called vivid, or experientially rich, memories, and would likely not require much hippocampal participation to retain or retrieve them. The source of the difference between our findings and theirs more likely lies in the kind of memories sampled (vivid vs impoverished) rather than only in differences of lesion location and extent in the two populations. Furthermore, we note that the pre-operative temporal-lobe epilepsy patients studied by Viskontas et al (2000) were equally impaired in retrograde memory as those who had undergone temporal-lobe resection, which clearly involved a considerable extent of removal of temporal neocortex.

Even MTT, however, posits that the amount of MTL damage should correlate with the severity and extent of retrograde amnesia for autobiographical events. Using MRI volumetry in a group of mild to moderate AD patients, Gilboa et al. (submitted b) found a strong correlation between extent of remaining tissue in bilateral MTL and anterior lateral temporal cortex on the one hand, and retrograde autobiographical memory loss, on the other, although the pattern was not sensitive to the age of the memory tested. No such correlation, however, was evident in a study of patients with focal lesions (Kopelman et al., 2003). Exactly what accounts for this discrepancy remains to be determined.

Likewise, there is disagreement concerning the effects of semantic dementia (SD) on autobiographical memory loss (see Graham & Hodges, 1997; Graham, Patterson, & Hodges, 1999; Murre et al., 2001). Neural degeneration associated with SD affects primarily the anterior and lateral temporal cortex, typically on the left, leaving the MTL relatively spared (Mummery, Patterson, Price, Ashburner, Frackowiak, & Hodges, 2000). If remote autobiographical memories are represented in neocortex, as the standard model predicts, then patients with SD should show impaired memory for remote events but preserved memories for recent ones, a pattern opposite to that which the consolidation model predicts for amnesia. This is exactly what Graham et al. (1997) reported.

Westmacott, Leach, Freedman, and Moscovitch (2001), however, argued that this pattern is observed only because patients with SD do not have the verbal means necessary to comprehend and express themselves adequately. Given non-verbal cues, such as family photos of particular events, and the opportunity to communicate by gestures, intonation, and so on, the SD patient tested showed that remote autobiographical memory was relatively preserved, a finding corroborated by Moss et al. (2003), Ivaniou, Cooper, Shanks, and Venneri (2003), and Piolino et al. (2003). Graham et al.'s patients, however, continued to be impaired in retrieving all memories except those from the last two years, even when they were tested using Westmacott et al.'s methods (Nestor, Graham, Bozeat, Simons, & Hodges, 2002).

The source of the discrepancy among these studies remains unknown. A likely possibility is that the extent and locus of degeneration differs among patients, but whether the differences lie in MTL, anterior and lateral temporal lobes, or even prefrontal cortex (PFC), has yet to be determined.

Summary. The results of lesion studies are more variable than those from neuroimaging studies, because the methods used differ across studies, as do the size and location of lesions and degeneration. On balance, however, the results favor the MTT: Damage to the hippocampal complex leads to temporally extensive loss of detailed autobiographical memories. These lesion findings indicate not only that the hippocampus is implicated in the retention and retrieval of these memories, as neuroimaging studies had already shown, but that it is essential for these functions. Some questions remain to be resolved: Is the severity and temporal extent of the autobiographical memory loss related to the size of MTL lesions or degeneration, and does degeneration of anterior and lateral temporal cortex in SD spare recent, but not remote, memories?

Parallels between anterograde and retrograde memory: A common mechanism?

The evidence from studies of retrograde amnesia—that the MTL, and particularly the hippocampus, is needed for retention and retrieval of rich autobiographical memories, or re-experiencing of past events—dovetails with emerging evidence from studies of anterograde memory. As we noted earlier (p. 4), Tulving (1985) distinguished between two aspects of recognition, and of memory in general: *recollection* and *familiarity*. Aggleton and Brown (1999), working in a somewhat different tradition, had already distinguished between the extended hippocampal system, which is needed for recall, and the peri-rhinal system, which suffices for recognition (see above, p. 6). Investigators were quick to see the parallels between Aggleton and Brown's proposal and Tulving's distinction between recollection and familiarity (Yonelinas, 2002).

A number of studies showed that recollection was disproportionately impaired following lesions that included the hippocampus, whereas familiarity was relatively spared (Holdstock et al., 2002a, b; Mayes et al., 2003, 2004; D. Moscovitch & McAndrews, 2000; Yonelinas et al., 2002). Concurrently, neuroimaging studies appeared which showed that the hippocampus was activated preferentially during recognition of items that were recollected as compared to those which were only considered familiar (Dolcos et al., 2002; Eldridge, Knowlton, Furmanski, Bookheimer, & Engel, 2000; Davachi, Mitchell, & Wagner, 2003). Our own preliminary findings (Caza et al. , 2004) have shown that even for recognition of newly learned associations, those which are accompanied by recollection show the greatest hippocampal activation. This finding emphasizes that recollective experience, rather than simply the retention and recovery of newly-formed associations, is the salient factor in hippocampal memory processes.

These studies on recollection and familiarity in anterograde memory add the virtue of parsimony to the MTT: The same processes which implicate the hippocampus in anterograde memory also implicate it in remote memory. If we accept this evidence, there is neither need nor reason to believe that the functions and representations that depend on the hippocampus during recent memory, stop depending on it for remote memory. According to this belief, which forms the basic tenet of the standard model, other structures, which did not possess the capability initially to support recollection, would assume that function once consolidation is complete. Even if this were biologically plausible, it adds complexity where complexity is not needed.

It is important in all of these discussions to emphasize that when we say that representations depend on the hippocampus or are mediated by it, we do not mean that they reside there, any more than that a melody resides in the keys of a piano (Wechsler, 1963). As argued by us (Nadel & Moscovitch, 1997, 1998) and others (P. Milner, 1989; Teyler & DiScenna, 1986), the hippocampus contains sparse codes that bind and orchestrate information that is distributed in many brain regions into a multifaceted memory of a past experience. Without hippocampal involvement, that information cannot be unraveled in a way that would capture the experience. In short, the hippocampus allows re-experiencing to occur. To push the musical analogy further, the hippocampus provides the score that is crucial for orchestrating the music which emerges from the neocortical players.

Semantic memory for facts, events, people, and words

Damage to extra-hippocampal structures in the medial temporal lobes can lead to loss of remote memories for facts, events, and people, with the latter being particularly associated with damage to the anterior temporal pole (Tranel, Damasio & Damasio, 1997). Loss of semantic memory, including loss of vocabulary and conceptual knowledge, is associated with damage to posterior neocortical structures, particularly the lateral aspects of the temporal lobe.

It is not known which areas are implicated in the loss of personal semantics. Semantic loss is evident in many patients with dementia and neocortical degeneration, including people with semantic dementia whose MTL is relatively spared (Graham & Hodges, 1997; Snowden, Griffiths, & Neary, 1994, 1996), as is their autobiographical memory (Kitchener and Hodges, 1999). As noted earlier, although there is controversy as to whether people with SD have a memory loss for remote, autobiographical events, there is agreement that semantic memory is impaired except for information acquired or used most recently.

With respect to amnesia associated with MTL damage, investigators of all theoretical persuasions agree that loss of pre-morbid semantic memory following MTL damage is temporally-limited, with remote memories being more resilient, a pattern opposite to that observed in SD (Fujii et al., 2000; Manns, Hopkins, & Squire, 2003; Murre et al., 2001). This stands in stark contrast to the extensive retrograde loss of autobiographical memory in people with MTL lesions.

These differences between SD and MTL amnesia are illustrated in Figures 6 and 7 where we can compare the performance of K.C., a person with large bilateral, hippocampal lesions (Figure 6), to that of E.N., a person with semantic dementia (Figure 7) (Wetmacott et al, 2001; Westmacott and Moscovitch, 2002). Despite having widespread damage in other cortical and subcortical areas (see Rosenbaum et al., 2000, in press), K.C.'s intelligence is in the normal range as is his knowledge of words and people for all time periods except for the 5-10 year period immediately preceding his accident, and at all times subsequent to it. By comparison, E.N.'s recent memory for words and names is better than her remote memory for them.

We interpret the performance of E.N. as showing that the medial temporal lobes, which are relatively preserved in her, can mediate retrieval of semantic memory because they still retain some autobiographical significance, mediated by the hippocampus, and it is by virtue of this experience-

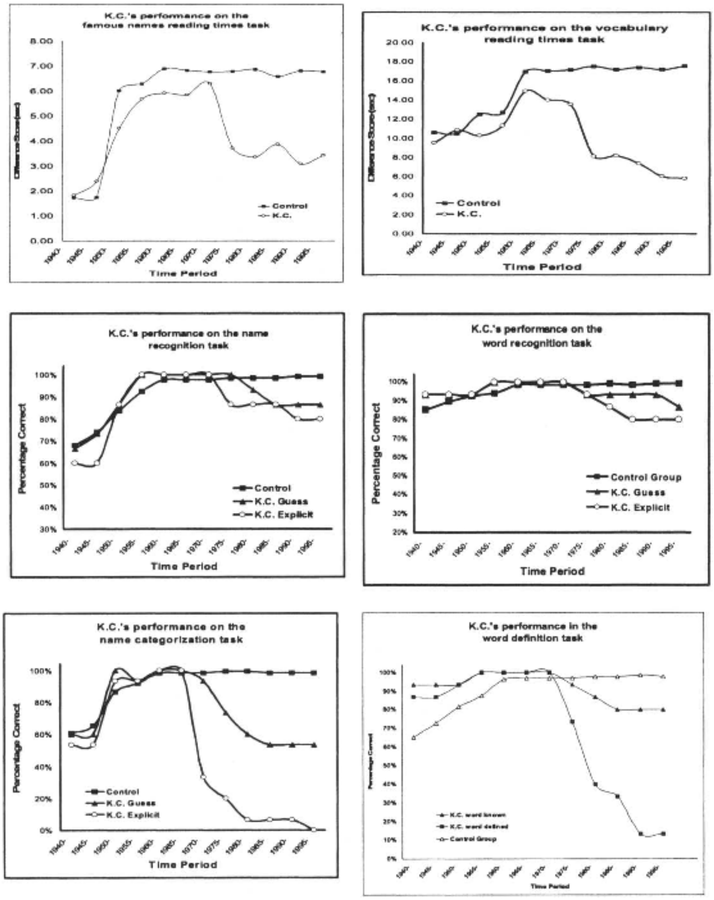


Fig. 6. Performance of healthy controls and K.C., an amnesic person with bilateral hippocampal lesions, on tests of semantic memory. **Left panel, Famous Names:** *top:* Difference in reading time (sec/list of 15 words) between unfamiliar names and names of people who became famous in each of five year periods between 1940 and 1995. The greater the difference, the more familiar the name is to the person being tested. K.C. sustained his injury in 1981. *Middle:* Percent correct responses in a three-alternative forced-choice in which participants selected the name belonging to a famous person. Confident responses are compared to guesses. *Bottom:* Percent correct responses in a three-alternative forced choice in which participants select the appropriate category (e.g., politician, actor, athlete). Confident responses are compared to guesses. **Right panel, Words:** The measures are the same as in the left panel, except that participants now are tested on words that entered the language in each of five year periods between 1940 and 1995. (Modified from Westmacott & Moscovitch, 2001, 2002; Wesmacott et al., 2002).

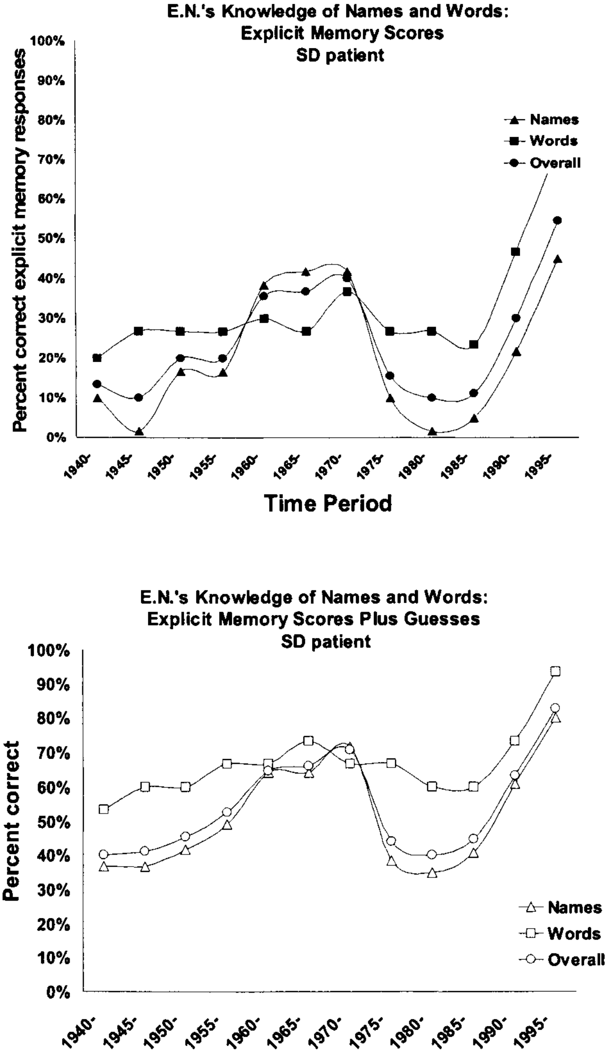
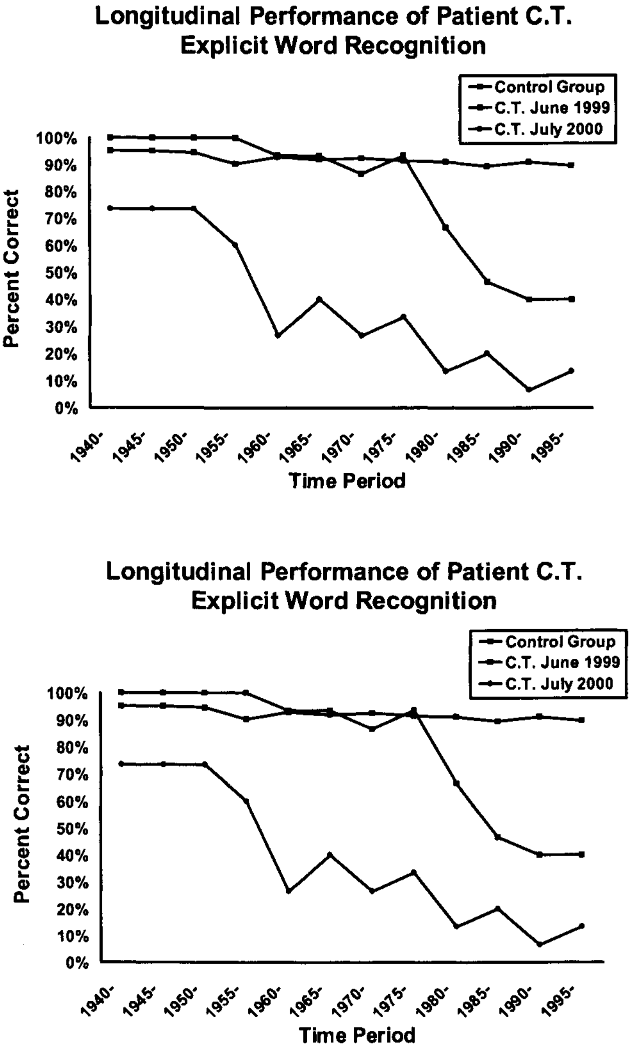


Fig. 7. Performance of E.N., a person diagnosed with semantic dementia, on tests of semantic memory. **Names and Words**: Percent correct responses in a three-alternative forced-choice in which participants selected the name belonging to a famous person from two non-famous names, and the real word from two non-words. **Top panel** shows only confident responses. **Bottom panel** combines the score from confident responses and guesses. Healthy controls scored over 90% correct with no change across time. (From Westmacott & Moscovitch, 2002).

based trace that the "semantic" memory is recovered. In people with degeneration of the MTL and lateral and anterior temporal cortex, as occurs in Alzheimer's Disease (AD), the losses resulting from damage to both structures combine, and we observe an extended and graded retrograde amnesia for names and words that seems to be related to the severity of the disorder (Westmacott & Moscovitch, 2003, and Figure 8 a). As the disease progresses, the gradient extends further back in time (Figure 8 b). The implication of these findings, and of similar ones reported by Piolini et al. (2003), is that the most remote semantic memories are represented more strongly in the neocortex, or distributed more widely, so that they are less vulnerable than more recently-acquired memories to neuronal degeneration or loss.

Recent evidence from studies on the acquisition of semantic memory in children whose hippocampus was damaged at birth, or shortly thereafter (Vargha-Khadem et al., 1997, Gadian, Aicardi, Watkins, Porter, Mishkin, Vargha-Khadem, 2000)., and in adults with hippocampal lesions (Kitchener, Hodges, & McCarthy, 1998; O'Kane, Kensinger, & Corkin, 2004; Skotko et al., in press; Van der Linden, Cornil, Meulemans, Ivanoiu, Salmon, & Coyette, 2001; Westmacott & Moscovitch, 2001), suggests that acquisition of semantic memory is not dependent on the MTL, but certainly benefits from it (but see Kitchener & Squire, 2000). Neuroimaging studies support these observations. In a test of memory for faces of famous people, which can be considered a test of semantic memory, Haist, Bowden Gore, and Mao (2000) found greater activation in the entorhinal cortex for faces of people who became famous in the most recent decade than in all other decades. Similar findings were reported by Leveroni et al. (2000). This 10-year gradient is consistent with that reported in lesions studies (Manns et al., 2003; Westmacott et al., 2001,2002).

Taken together, the results from the lesion and neuroimaging studies speak to a fundamental distinction between remote memory for episodic and semantic information. Whereas detailed memory for autobiographical episodes is dependent on the medial temporal lobes for as long as the memory exists, memory for semantic information benefits from the MTL (hippocampus and peri-hippocampal cortex) for only a limited time, and can be acquired, slowly and with difficulty, without it. Observations regarding the fate of remote semantic memory, and the acquisition of new semantic memory, following medial temporal and neocortical lesions and degeneration are consistent both with the traditional model and MTT, although the mechanisms used to explain the findings differ. We discuss these alternatives next.



Longitudinal Performance of Patient C.T. Explicit Word Recognition

Longitudinal Performance of Patient C.T. Explicit Word Recognition

Fig. 8. Performance of C.T., a person diagnosed with Alzheimer's Disease in the mid-1990s, on tests of semantic memory. Percent correct responses in a three-alternative forced-choice in which participants selected the name belonging to a famous person from two non-famous names **(top panel)**, and the real word from two non-words (**bottom panel**). The person was tested at two intervals, a year apart, to chart the decline. Only confident responses are displayed. (From Westmacott, Freedman, et al., 2004).

Prolonged consolidation for semantic memory: Two alternatives

MTT provides the following account of the interaction of episodic with semantic memory. Whereas each autobiographical memory trace is unique, the creation of multiple, related traces facilitates the extraction of the neocortically-mediated information which is common among them, and which is shared with other episodes. This information is then integrated with preexisting knowledge to form semantic memories that are represented permanently in neocortical structures specialized in processing the information and capable of being modified while doing so. Eventually, those memories can be retained and retrieved independently of the hippocampal complex. This process of memories becoming increasingly semantic or generic, was first proposed by Cermak and O'Connor (1984; Cermak, 1989) to explain the preserved memories, both personal and public, of amnesic people.

According to the standard model, however, the memory that is held temporarily in the medial temporal lobes is identical to the memory that later is stored permanently in neo-cortex. Indeed, many believe that prolonged consolidation effects a transfer of the same memory from one location to another by strengthening neocortical connections (see Kandel, 2001, p. 1038).

MTT assumes, on the other hand, that the temporary MTL memory is fundamentally different from the permanent neocortical one. The former retains its episodic flavor, such that the semantic content is tied to the spatio-temporal (autobiographical) context in which it was acquired. The latter is stripped of its episodic context and retains only the semantic core (see illustrations in Figure 9). By this view, prolonged consolidation refers to the establishment of a semantic trace that can survive on its own, but it does not entail the loss of the episodic trace, nor is it identical to it (see McClelland, McNaughton, & O'Reilly, 1995, for a computational model which argues for the necessity of two distinct memory systems and how the episodic contributes to the semantic, and Murre et al., 2001 for review of models of retrograde amnesia and semantic dementia). Indeed, according to MTT, the two types of memories can co-exist, so that one can have both an episodic and a semantic representation of the same event, object, person, or fact, and that one can lose one kind of representation without losing the other (see Figure 10). These alternative interpretations make different predictions which we have tested both in humans and in nonhumans (see Rosenbaum, Winocur, & Moscovitch, 2001).

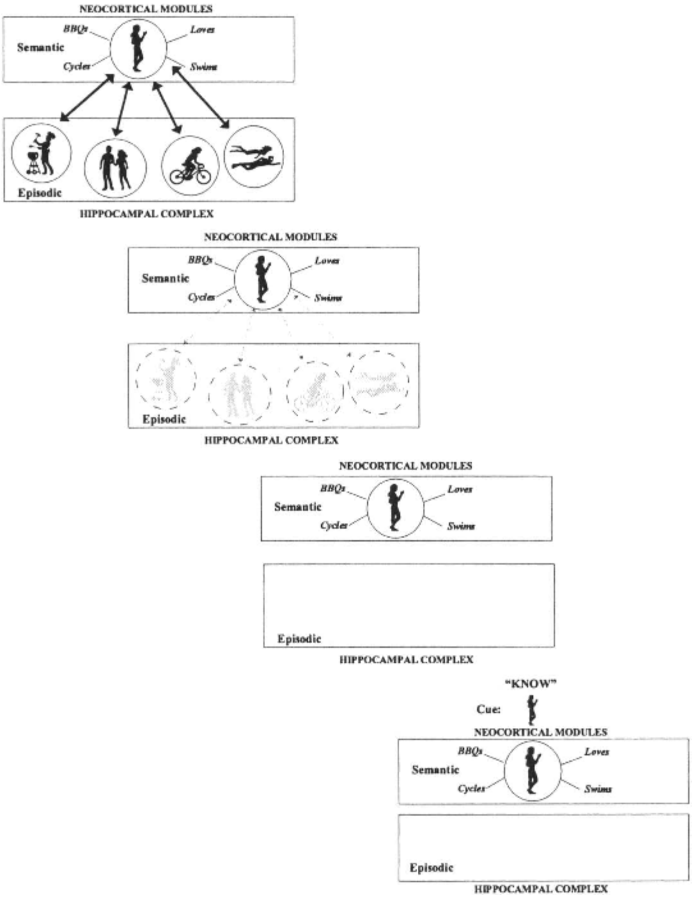


Fig. 9. The presumed, normal loss of episodic memory with time, with memories becoming increasingly semantic. The relation between hippocampus and neocortex in representing episodic and semantic memory during this process is also depicted. The top panel shows that shortly after engaging in an event with a person, such as swimming or cycling, autobiographical memories of the events are represented in the hippocampal complex with links to neocortex where semantic knowledge about the person, that she likes to cycle and swim, is also represented. With time, details of the autobiographical memories fade. In the end (bottom panel), what remains is only semantic knowledge about the person, represented in neocortex. Thus, one is left knowing many things about the person, but without having any autobiographical episodes associated with that knowledge. You only "know" that person but cannot "recollect" anything about her.

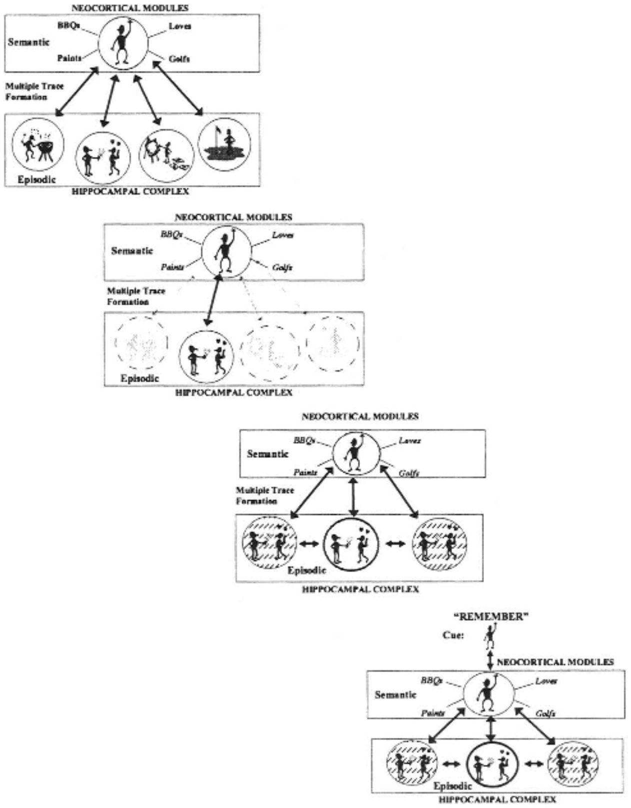


Fig. 10. The presumed, normal loss of episodic memory with time, with most memories becoming increasingly semantic, except that some autobiographical memories are preserved . The relation between hippocampus and neocortex in representing episodic and semantic memory during this process also is depicted. The top panel shows that shortly after engaging in an event with a person, such as swimming or cycling, autobiographical memories of the events are represented in the hippocampal complex with links to neocortex where semantic knowledge about the person, that he likes to golf and that he is romantic, is also represented. With time, details of most of autobiographical memories fade. The romantic encounter with the person, however, is recollected, and in doing so, is re-encoded as a memory, as described by MTT. As a result, there are multiple traces of that episode, each mediated by hippocampal-neocoritcal ensembles. In the end (bottom panel), one is left with many semantic memories associated with the person, which are represented in neocortex, but also with a few autobiographical memories of him. Thus, one not only "knows" many things about the person, but one can also "recollect" or "remember" some autobiographical episodes associated with him.

The evidence from people with semantic dementia supports the MTT interpretation. People with SD read and recognize names of countries, cities, landmarks, people, and even common objects better if they have episodic or personally-significant memories associated with them (Graham et al., 1998; Snowden et al., 1994, 1996; Westmacott et al., 2001) than if they do not. Having lost semantic representation as a result of neocortical degeneration, people with SD rely on their relatively preserved MTL to represent these items within an autobiographical context. Put in other words, they *recollect* these names, events, and objects, rather than *know* them, in contrast to what the rest of us do. Conversely, amnesic people with medial temporal damage will recognize objects, words, and individuals regardless of their autobiographical significance, but will not be able to conjure an autobiographical event related to them (Westmacott et al., 2001).

MTT helps account for the different memory gradients in amnesia and semantic dementia. In semantic dementia, recent memories, both episodic and semantic, can be supported for a while by their relatively preserved MTL, perhaps by providing tonic input and support to degenerated neocortical neuronal ensembles. Alternatively, and more plausibly, their behavior suggests that, in the early stages of semantic memory acquisition, there is an episodic component to semantic knowledge that contributes to retention and retrieval. That is, the information is represented simultaneously by the hippocampal complex-neocortical ensemble as an episodic memory and by the neocortex as a semantic memory (see Figure 8 and Nadel & Moscovitch, 1997, 1998; Nadel et al., 2003). Eventually, episodic support is no longer needed.

Unless they are rehearsed or revived, most hippocampally-dependent episodic memories fade within a relatively short time, leaving semantic memories primarily dependent on neocortex. Because their neocortex is degenerated, patients with SD cannot support remote semantic memories unless they are also represented in the hippocampal complex, as is the case for cities, countries, and landmarks which the patient remembers visiting. By contrast, amnesic patients with MTL damage cannot form new, elaborate semantic memories although they can gain some familiarity with new vocabulary and names of famous people (Corkin, 2002; Wesmacott et al., 2001; but see Kitchener et al., 1998; Van der Linden et al., 2001, for cases of well-preserved semantic memory acquisition). Older semantic memories, which were assimilated into the amnesic person's general knowledge, are retained well, and can be normal.

Test of the standard model's and MTT account of the pattern of semantic memory loss in amnesia and dementia

To test the two models, Westmacott and I (Westmacott & Moscovitch, 2003; Westmacott, Black et al., 2004) examined performance on two semantic memory tasks: fame judgment and speeded reading of names of famous people. According to traditional consolidation theory, both types of knowledge should be represented in neocortex if the names are not recent. MTT, other hand, predicts that insofar as the ostensibly semantic memory has autobiographical significance, that component of the memory is dependent on the hippocampal complex for both recent and remote names.

To obtain an independent measure of semantic and episodic components of name knowledge, we had a group of control participants make recollection (R) or familiarity or know (K) judgments to names. Westmacott and I were able to select 25 names which consistently were rated as R and another 25 which consistently were rated as K, and which were matched for length, familiarity, and the amount of semantic knowledge participants had about them (see Figure 11).

Armed with these well-matched norms for a sample of names, we used them in our tests of fame judgment and speeded reading which we administered to a separate group of control participants who were not involved in collecting the norms. We found that reaction times (RTs) for fame judgments and speeded reading were significantly faster (by about 50 msec) for names with high R ratings as compared to those with low R (or K) ratings. RTs to non-famous names were about 200 msec slower (Westmacott & Moscovitch, 2003) (see Figure 12 a, b).

If, as MTT predicts, the advantage of high R over low R names is dependent on the hippocampal complex, then the advantage should be diminished or absent in people with damage to those structures who have poor episodic memory, such as people with amnesia or with Alzheimer's disease. People with SD, on the other hand, should retain the high R advantage even though they have neocortical degeneration accompanied by semantic memory loss. If, however, high R responses to old names are neocortically-mediated, as the standard model predicts, then performance on high R names should not be selectively impaired in amnesia, but should be impaired in AD and SD.

In accordance with MTT, but against the standard model, we found that the R advantage was lost in all four of the people with amnesia, and in all but one of over a dozen people with AD whom we tested (see Figure 11 a, b). By contrast, the two people with SD whom we tested showed a height-

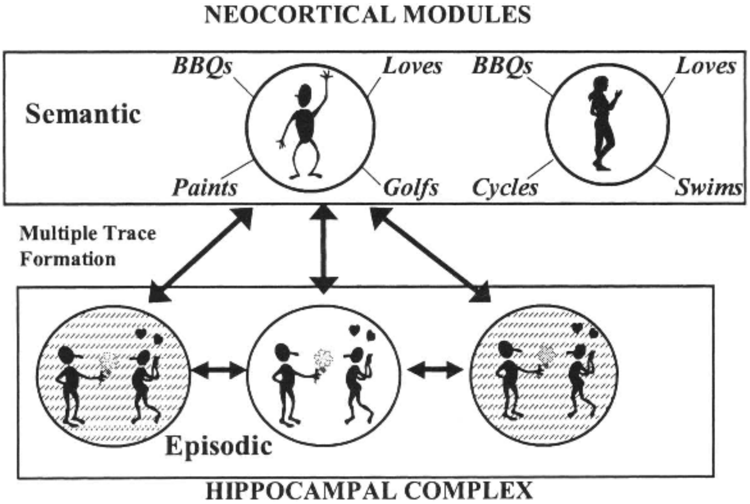


Fig. 11. The neural representations associated with people about whom one has both semantic and autobiographical memories (one both "knows" and "remembers" that person, see Figure 10), and about whom one has only semantic knowledge (one only "knows" that person, see Figure 9).

ened R advantage (see Figure 11 c). Thus, although tests of fame judgment and speeded reading are ostensibly semantic, our results show that they should more properly be considered tests of knowledge to which both semantic and episodic memory can contribute (Westmacott, Black, et al., 2004).

After completing the RT tests, we had our participants rate the names they had seen as R or K. In line with our findings on the RT test, we found that people with amnesia or Alzheimer's Disease gave R ratings to far fewer of the names than did the controls; in some cases, none of the names received an R rating. In contrast, the SD patients gave a larger than normal proportion of R ratings to names which they recognized (Westmacott, Black et al., 2004).

Taken together, these results favor the MTT interpretation of the preservation of remote semantic memory over the interpretation provided by the standard model. Remote semantic memories are different from their recent counterparts. Typically, they contain information only about the semantic core, without the context in which that information was acquired. This semantic knowledge is represented in extra-hippocampal structures. The autobiographical significance that may also be associated with that knowledge, on the other hand, is dependent on the hippocampus. When it is first

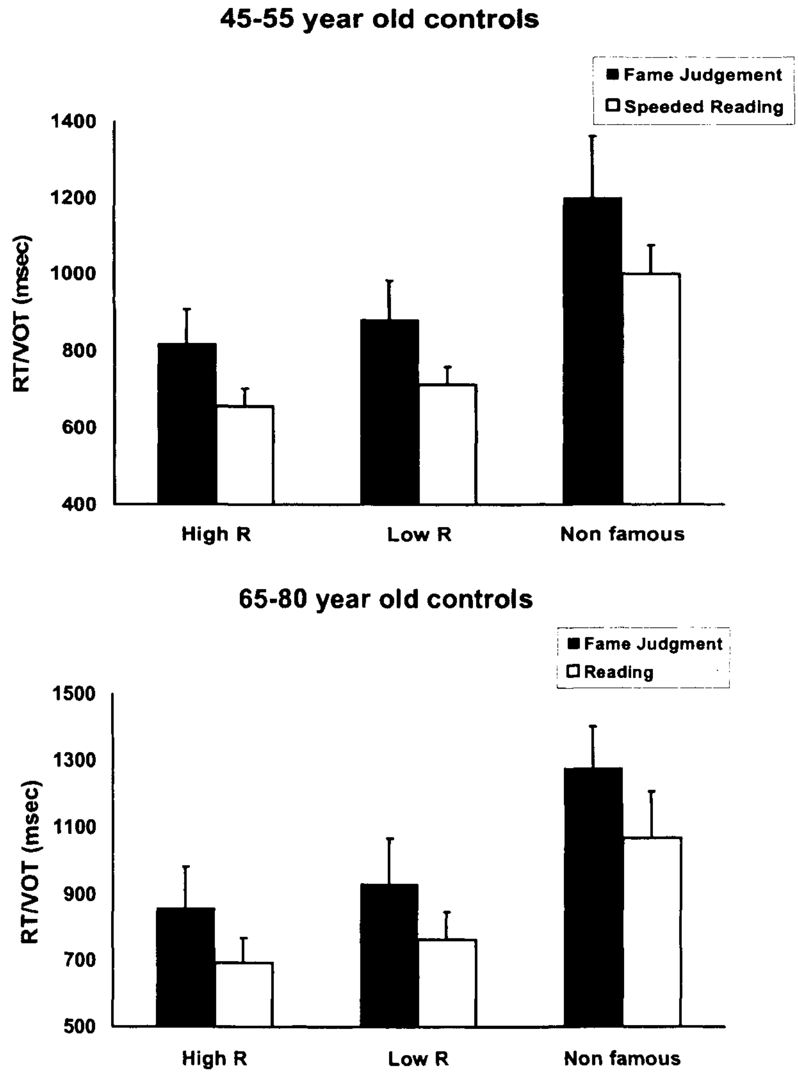


Fig. 12. Mean reaction times in msec (and standard error of the mean, SE) to make fame judgments, and voice onset times in msec (SE) to read names of famous or non-famous people. The famous names were rated as reliably eliciting recollection in the cohort (High R) or as unlikely to elicit recollection (Low R). Participants were healthy controls between 45-55 years old (top panel) or 65-80 years old (bottom panel). (From Westmacott & Moscovitch, 2003).

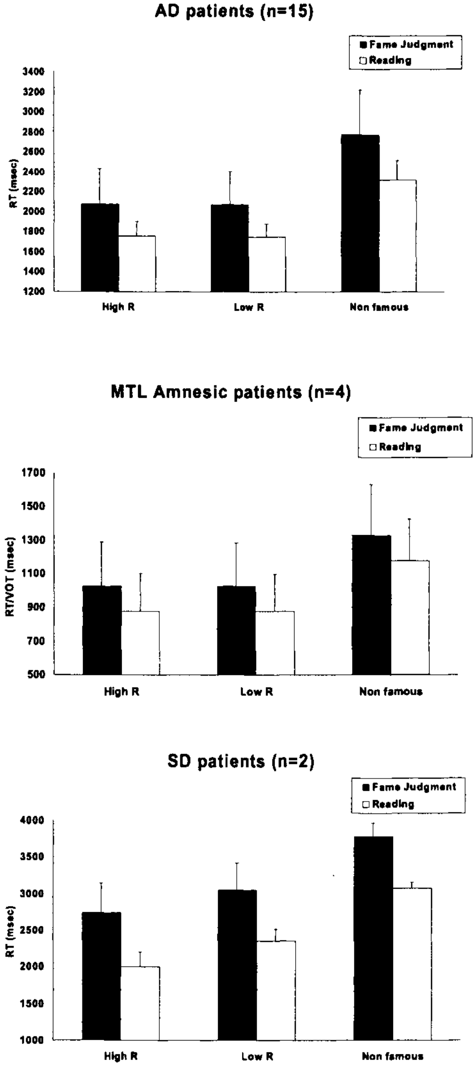


Fig. 13. Mean reaction times in msec (and standard error of the mean, SE) to make fame judgments, and voice onset times in msec (SE) to read names of famous or non-famous people. The famous names were rated as reliably eliciting recollection in the cohort (High R) or as unlikely to elicit recollection (Low R). Participants were patients diagnosed as having Alzheimer's Disease (AD) (top panel), patients with medial temporal lobe (MTL) lesions (middle panel), and patients diagnosed as having semantic dementia (SD; bottom panel). (From Westmacott, Black, et al., 2004).

acquired, semantic knowledge often may be very highly associated with autobiographical context, and may need to be recovered via that route.

Summary. Unlike episodic memory, semantic memory for public events, people, vocabulary, and even facts about oneself (personal semantics) shows only a temporally-limited retrograde amnesia, lasting about ten years, in people with medial temporal/hippocampal lesions. Moreover, there are even cases showing that acquisition of semantic memory is possible after hippocampal lesions, although in most (but not all) cases learning is slow and the memory is not always elaborate. These findings are consistent with MTT and the standard model.

In comparison to the standard model, however, MTT argues that the "semantic" memory that benefits from hippocampal involvement during the initial period is not identical to the one that is retained after that initial vulnerable period has passed. What appears to be memory consolidation really is memory transformation, from a (semantic) memory embedded in a rich context to one in which the context has been lost, or become impoverished, so that only the semantic core remains. Evidence from humans (and rats, Rosenbaum et al, 2001) supports this idea, and also demonstrates that the two types of "semantic" memories can co-exist and contribute to performance in healthy people (and in rats).

Conclusion

The evidence reviewed suggests strongly that the function of the hippocampus (and possibly related limbic structures) is to help encode, retain, and retrieve *experiences*, no matter how long ago the events comprising the experiences occurred. Episodic or autobiographical memories are not comprised simply of the content of the event or the associations that make up the experience, but of the experience itself, insofar as that is possible. What this means is that some conscious awareness is bound up with that experience (in common parlance, that is what experience would imply—having a non-conscious experience would simply be described as an event that happened to oneself but that one did not really experience).

This view of the function of the hippocampus borrows from Tulving's (1985) distinction between recollection and familiarity or knowing, and applies it to the component process model (Moscovitch, 1992, 1994, 1995, 2000; Moscovitch & Umilta, 1990, 1991; Moscovitch & Winocur, 1992, 2002) which states that the hippocampus is a structure that obligatorily encodes all information in conscious awareness. Via its connections with the neocortex and other structures, the hippocampus binds the elements of the experience, and the consciousness that accompanied it, into a memory trace.

The hippocampal component of the memory trace is a sparsely-distributed code that acts as a pointer or index to the brain regions that represent elements of the experience (Teyler & DiScenna, 1986). It is via that pointer or index that the memory trace is reactivated so that the event can be re-experienced. Thus, although the memory of the experience is dependent on the hippocampus, it does no reside there, but is distributed throughout those regions of the brain that represent the multifaceted elements of the experience and that are reactivated in concert by the hippocampus.

Emerging evidence from studies of recently-acquired memories in the laboratory suggests that it is recollection, i.e., memory of an experience, that is particularly dependent on the hippocampus. Developing MTT, Nadel and I (1997, 1998; Moscovitch & Nadel, 1999; Moscovitch et al., 1999) proposed that the same applies to remote memories: Detailed memories of autobiographical episodes always depend on the hippocampus no matter how long ago they were formed. Contrary to the standard view, such memories are not consolidated elsewhere in the brain.

By contrast, semantic memories of public events, of people, of vocabulary, of facts about oneself (personal semantics), and even of the gist of events without their experiential component (familiarity without recollection), can be represented without the hippocampus, though it may benefit initially from hippocampal involvement. Memories which appear to be consolidated with time on closer inspection seem to be transformed from those which are experientially-based to those which are more semantic. The evidence that we have reviewed from lesions and neuroimaging studies is, for the most part, consistent with these proposals, though some issues remain to be resolved. MTT provides a parsimonious view of memory and hippocampal function across time, from anterograde to retrograde: As long as the memory is experiential, it will always depend on the hippocampus.

Making experience and re-experience the foundation of hippocampal memory opens many new problems. We do not know what it truly means to travel back in time and re-experience an event. Nothing is re-experienced as it had occurred. Memory is reconstructive, not reduplicative, of experience. Furthermore, as Gilboa (2004) noted, we do not have direct measures of what constitutes the experiential part of memory. Instead, we have to rely on close correlates, such as the number of details, and ratings of vividness and personal significance (Addis et al., 2004a; Gilboa et al, 2004; Levine et al, 2002; Moscovitch et al, 1999). Using judgments of recollection gets at the same thing. All of these, except actually measuring the number of details one can remember, are subjective measures which carry problems of their own. Nonetheless, rather than revert to some objective measure which does not capture the essence of re-experiencing, new procedures can be developed that will allow us to investigate the implications of an experientially-based view of memory and hippocampal function in humans and other animals (see Rosenbaum et al., 2001; Eichenbaum, 2001; Fortin, Agster, & Eichenbaum, 2002; Fortin, Wright, & Eichenbaum 2004; Martin, de Hoz, & Morris, in press; Winocur, 1990; Winocur, MacDonald and Moscovitch, 2001; Winocur, Moscovitch, Caruana, & Binns, submitted).

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