In Opposition to Inhibition

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I. Introduction

> "What does inhibition in psychology mean? Most psychologists have presupposed that its meaning in psychology is practically the same as in physiology. They begin with illustrations of neural inhibition and end with illustrations of inhibition among ideas." (Breese, 1899, p. 6)

The concept of inhibition is firmly entrenched in our language and in our thinking, both in our everyday lives and in our scientific theorizing. We are used to the idea that an impulse, a thought, or an action can be expressed or it can be withheld. To see that this is so, we need only turn to the source of (almost) all quotes for matters psychological, William James. In his chapter on functions of the brain, James (1890, Vol. I, p. 67) says: "Inhibition is a *vera causa*, of that there can be no doubt." He as readily acknowledges its role in behavior (James, 1904, p. 178): "Voluntary action, then, is at all times a resultant of the compounding of our impulsions with our inhibitions." Lest there be any remaining uncertainty about his position, he concludes in his chapter on will (James, 1890, Vol. II, p. 583, his italics) that "*Inhibition is therefore not an occasional accident; it is an essential and unremitting element of our cerebral life*."

According to the *Oxford English Dictionary*, the derivation of the word *inhibition* lies in the Latin verb *inhibere* (cf. *in* + *habere*, literally, to "hold in" or to restrain); hence the basic idea has a long history. By the fourteenth century, the Latin word gave rise to the Old French *inibicion* (used initially in the legal sense of prohibition). The *OED* lists four very related senses of the word: (1) "the action of inhibiting or forbidding;" (2) in law, the act of prohibition; (3) "the action of preventing, hindering, or checking;" and (4) "a voluntary or involuntary restraint or check." These four senses demonstrate the breadth in use of the term. It is also in widespread use: Its mean familiarity rating in the MRC database (Wilson, 1988) is almost precisely at the 50th percentile.

In their psychological dictionary, English and English (1958, p. 262) discriminate three senses of the concept inhibition. We will refer to these senses as suppression, restraint, and blocking. *Suppression* pertains to the prevention of a process from beginning or from continuing once begun, encompassing both psychological and physiological processes. *Restraint* refers to a mental state in which behavior is difficult to initiate or is curtailed. *Blocking* represents the classic psychoanalytic sense wherein a process, seen as instinctual, is kept from coming into consciousness (in psychoanalytic theory, by the activity of the superego).

To a psychologist, there are two principal applications of the concept of inhibition. The first applies to the nervous system: Neurons can serve either excitatory or inhibitory functions. The second applies to thought and behavior: Cognitive processes—thoughts—can be activated or inhibited. In this chapter, our purpose is to hold the *cognitive* concept of inhibition under the light. We wish, therefore, to make clear from the outset that this chapter is *not* about the neural concept of inhibition, with which we have no quarrel. But despite the emphasis in neuroscience—especially in cognitive neuroscience—on relating mind mechanisms to brain mechanisms, we *do* wish to question the cognitive concept of inhibition, suggesting that the evidence for such a mechanism is disputable, and that there are problems with the concept itself.[1]

The core of the problem is that the concept of inhibition at the cognitive level cannot derive directly from the concept of inhibition at the neural level. We believe that such reification creates a false sense of comfort in theorizing. Put starkly, an electro-chemical impulse in a neuron cannot possibly explain a thought, despite being intimately involved in providing the means for that thought to occur. Of course, the cognitive software runs on the neural hardware;

we are not neuro-Luddites. But we would no more expect to find cognitive inhibition because there is neural inhibition than we would expect to find cognitive glia or cognitive ion channels because their neural counterparts demonstrably exist. To stress this point, we also do not see a necessary connection between cognitive activation and neural excitation. The level of analysis is entirely different.

As researchers, it is certainly a laudable and appropriate goal to link brain to mind—this is unquestionably one of the most important and exciting frontiers of science today—but we must not expect the mechanisms that brain and mind use to be the same. Marr (1982) distinguished three levels of analysis at which we must understand a machine that is processing information: computational theory, representation and algorithm, and hardware implementation. [To understand their application to cognition, a good place to begin is with the exchange between Broadbent (1985) and Rumelhart and McClelland (1985) concerning the McClelland and Rumelhart (1985) distributed memory model.] Our view is that inhibition at the level of hardware implementation in the nervous system may inform, but should not be confused with, psychological theory, which is usually at the level of representation and algorithm. Nor should it be confused with the more formal computational analysis of the problem.

In this chapter, we will set the stage with a thumbnail sketch of the history of inhibition, and then narrow in on the cognitive concept. From there, we will present several "case studies" of cognitive phenomena in the domains of attention and memory, phenomena which have been widely seen as indicative of the operation of inhibition. We will argue that the inhibition accounts offered for these phenomena are far from unassailable, and that inhibition as a cognitive concept is home to several different ideas, not a single coherent idea. Along the way, we will develop an alternative non-inhibition account that appears to provide a reasonable explanation and to have some generality as a cognitive mechanism. We will conclude with a reconsideration of the meaning and place of inhibition in cognition, posing a challenge to theories of cognition.

II. A "*Reader's Digest*" History of Inhibition

Like the word itself, the origin of the concept of inhibition lies not in the nervous system, but in the realm of mind and behavior. Diamond, Balvin, and Diamond (1963) and Smith (1992) both provide thorough and engaging accounts of this history, accounts to which we cannot do justice here, but upon which we will rely heavily for our sketch. The story begins with the mind-body problem, with emphasis on how the mind's control of the body is a continual struggle. In *Phaedrus*, Plato saw the will as a charioteer attempting to control two horses, one of desire and one of reason. Both Hippocrates and Aristotle wrote of how two simultaneous stimuli were not independent, with each influencing the other. Buddhism (see Warren, 1896) emphasized reaching a level of "cessation" where all bodily functions are arrested. Over a millennium and a half later, Descartes and Locke saw will as controlling action and emotion. This most fundamental duality has indeed probably always been with us. Control is essential, but does control require the counter-force of inhibition? For many, the answer is necessarily "yes"; our aim here is to question this response as it applies to cognition, not as it applies to the nervous system. First, however, we will briefly outline the history of the concept in both domains, beginning with the nervous system.

A. Neural Inhibition

Discussions of opposing forces in the nervous system can be dated back to Descartes (1650).[2] Yet in early neuroscientific research on the transmission of signals within the nervous system, neurons were thought to carry activation flowing in one direction in a single form: excitation (see, e.g., Müller, 1834). This framework appeared to be adequate for quite some time, until evidence began to accrue that the nervous system had to be more complex than such a conceptualization could reasonably capture. Bell (1823) was the first to clearly propose opposing forces, based on his experiments on the muscles of the eye. Bell unquestionably had the idea of inhibition, although without using the term (see also Bell & Bell, 1826). He even recognized the controversial nature of his idea, adding a footnote saying “The nerves have been considered so generally as instruments for stimulating the muscles, without thought of their activity in the opposite capacity” (Bell, 1823, p. 295).

But Bell’s work did not have much impact. Nor did Volkmann’s (1838) research demonstrating vagal inhibition of the heart in frogs, although when Weber and Weber (1845) tackled the same problem, their work did receive more attention.[3] According to Smith (1992), the word “inhibition” was first used in physiology in 1858, in an address given by Lister (1858) to the Royal Society of London, and then quickly came into common usage. Those looking for the point of origin of the concept of inhibition in physiology, however, often identify Sechenov’s (1863) discovery of central inhibition as the real breakthrough. Sechenov showed that brain structures in the frog could inhibit a spinal reflex, clearly much less of a “reciprocal” idea than its predecessors, which always proposed opposing forces at the same level. The fundamental opposition between excitation and inhibition was becoming a basic principle of the nervous system. In 1883, Brunton (p. 419) offered the classic definition of inhibition: “By inhibition we mean the arrest of the functions of a structure or organ, by the action upon it of another, while its power to execute those functions is still retained, and can be manifested as soon as the restraining power is removed.” Still, however, Meltzer (1899, p. 661) was able to say at the turn of the century that “the phenomenon of inhibition is distrusted in physiology.” That attitude changed with the century.

By the beginning of the twentieth century, inhibition in the nervous system was rapidly becoming more widely accepted. The name most often associated with the concept of neural inhibition is Sherrington (1906). He argued for the concept of neural inhibition not just at the neuronal level but also at the level of the organization of the nervous system. He was ultimately awarded the 1932 Nobel Prize for Physiology or Medicine for his research and writings that solidified the place of inhibition in neurophysiology. The nervous system now had inhibition: What about behavior and the mind? Two of Sherrington's contemporaries carried these banners: Pavlov and Freud. Their goal remained, though, to link behavior and mind to the brain and nervous system as directly as possible.

After his early work on the basic physiology of digestion and his discovery of conditioning, which won him the Nobel Prize in Physiology or Medicine in 1904, Pavlov devoted his later career to developing his laws of conditioning. For him, inhibition played the role of reducing a conditioned response in frequency or likelihood, and he distinguished two kinds of inhibition (Pavlov, 1928). The first was external inhibition, in which a new stimulus interferes with an existing response. The second was internal inhibition, in which a new conditioned response interferes with an existing unconditioned response. These ideas were absolutely central to his theory of learning and to his overarching goal of relating learning to processes in the nervous system.

Writing at the same time as Sherrington and Pavlov, Freud (1900, 1938) took as a fundamental premise of the mind the idea that impulses were sometimes suppressed or repressed. Inhibition was what made repression or suppression possible, and hence what permitted a civilized existence. For Freud, inhibition restrained the ego in two ways: (1) It minimized conflict with the id and the superego, and (2) it permitted a dampening of "psychic energy."

Smith (1992) suggests that Freud even recognized the duality of inhibition as both the process and the product of that process. More often, he focused on inhibition as product, and his sense of the word—stopping the expression but not the existence of an impulse—has come to be the most common sense of the word in everyday speech. As Pavlov brought inhibition to behavior, so Freud brought inhibition to the mind, both driven by the strong motive for a fundamental, physiologically based explanation.

B. Cognitive Inhibition

Inhibition has long been seen as a crucial element in a complete explanation of cognition. Early on, inhibition in thought was seen as suppression of movement (Ferrier, 1876; Ribot, 1889), a view that persisted into the early part of the twentieth century (Breese, 1899; Münsterberg, 1900). But then, with very occasional exceptions (e.g., Guthrie, 1930), inhibition disappeared as a cognitive concept and did not really re-emerge until the work of Postman and Bruner midway through the century (Postman, Bruner, & McGinnies, 1948; Bruner, 1957), as the influence of behaviorism began to decline.

The inclusion of inhibition in cognitive theorizing has, therefore, followed a quite slow time course. With the cognitive revolution of the 1950s, the concept reappeared, but gradually at first. In the “serial days” of the 1960s and early 1970s, when cognitive processes were seen as running off sequentially, activation was seen as the result of facilitation. Indeed, the terms “activation” and “facilitation” were often used interchangeably. Thus, semantic priming could produce a speeded response to decide whether *doctor* was a word in a lexical decision task when the preceding word was *nurse* rather than *bread* because *nurse* facilitated *doctor* by activating some of the relevant representational information in memory (Meyer & Schvaneveldt, 1976). Unlike in the domain of neuroscience, there was no need for a counteracting force in these early accounts, so inhibition had no place in cognition. Even the relatively few interference phenomena that existed, such as the Stroop effect (Stroop, 1935), were seen as the result of a kind of "tug of war" between competing tendencies: Activation of two representations, particularly because they were so related, made choosing the correct one difficult. Despite occasional references to the effect as "Stroop inhibition," it was generally called "Stroop interference." In this context at least, "interference" was seen as describing a behavioral situation whereas "inhibition" suggested an explanation of that situation.

Gradually, though, the concept of a force opposing facilitation and causing interference gained favor in cognition, as we will describe in the "case studies" that follow. Many labels have been used—repression, suppression, and inhibition being the most frequent among them—but inhibition has become by far the usual term, evidently because of the analogy to the operation of neurons. As Dagenbach and Carr (1994, p. xiii) put it, "we might speculate that the desire to have what is known about the way the nervous system works reflected in our cognitive models may be a relevant factor in renewed interest in inhibitory processes." As a result, the concept of inhibition has come to be widely used and widely accepted in cognition (see, e.g., the two recent edited collections by Dagenbach & Carr, 1994, and by Dempster & Brainerd, 1995).

C. Preface to the Case Studies

Whenever some experimental manipulation results in a decrease in performance relative to a specific baseline control condition, it has become the norm to refer to this as inhibition, in essence using the same word for both the mechanism and the phenomenon. Thus, in the case of response time, for example, any manipulation that speeds a response beyond its normal resting state, or baseline, is called facilitation; any manipulation that slows a response relative to baseline is frequently dubbed inhibition, not interference. A principal purpose of this chapter is to argue against this trend to routinely explain interference effects as due to inhibition, and instead to present an alternative account in terms of memory retrieval and the resolution of conflict between multiple response candidates. To build this case, we will rely on two sets of case studies, which form the empirical heart of this chapter.

We cannot survey and criticize all of the cognitive situations in which some form of the concept inhibition is used to explain behavior (see Arbuthnott, 1995, and Dempster & Corkill, 1999, for other, more favourable, overviews of inhibitory situations). Indeed, the very fact that there are so many different situations where inhibition is invoked demonstrates the "flexibility" of the concept, with its numerous nuances of meaning relating back to the three senses identified by English and English (1958). Instead, we have chosen to single out four well-known cognitive paradigms to illustrate our argument, two from the realm of attention and two from the realm of memory. Within each realm, we will present one example that we have explored in our laboratory and one studied in other laboratories. It has not escaped our attention that almost all of our illustrations have connections to cognitive research at the University of Toronto. The opportunity to relate our ideas to the work of our colleagues is a welcome one.

Our aim is to select cognitive paradigms and situations that are familiar in the field, ones with which inhibition accounts have been firmly linked and which have therefore served to move forward the "inhibition agenda." Under attention, therefore, we will illustrate with negative priming and inhibition of return. Under memory, we will use as examples directed forgetting and retrieval-induced forgetting. We will begin each sub-section with the inhibition account, then move to the non-inhibition account. At the end of each section, we will briefly allude to selected other phenomena where non-inhibitory accounts have been put forth as alternatives to existing inhibitory accounts, simply to show the diversity of the situations involved.

III. The Attention Case Studies

A. Negative Priming

The phenomenon that is probably most responsible for the rise in popularity of inhibition as an explanatory mechanism in cognition is *negative priming*. This was first observed by Dalrymple-Alford and Budayr (1966) in the context of the Stroop (1935) effect. That there is Stroop interference on incongruent color-naming trials (i.e., we are slow to say "yellow" to the word BLUE printed in yellow) indicates that we do not—and perhaps ordinarily cannot—ignore the word, at least not completely (see MacLeod, 1991, for a review). Now consider two consecutive Stroop trials, the first being the word RED printed in blue and the second the word GREEN printed in red. Responding "blue" to the color on the first trial necessarily means not responding "red" to the word. The problem is that "red" is the appropriate response on the second trial, after having just been ignored. Dalrymple-Alford and Budayr reported that interference was enhanced when the ignored word on the first trial became the attended color on the second trial, relative to sequences where successive words and colors were unrelated.

Negative priming lay dormant for a decade until it was revived by Neill (1977), Lowe (1979), and Tipper (1985), and has since become one of the most familiar cognitive tasks (for reviews, see Fox, 1995; May, Kane, & Hasher, 1995; Tipper, 2001). Most of the recent work has moved to the version of the task shown in Fig. 1 that permits more items/responses to be used. Two words appear on each trial. A cue (e.g., a particular item color; illustrated by italics in Fig. 1) indicates which is to be attended (the target in red) and which is to be ignored (the distractor in white). If the ignored word on the first (prime) trial becomes the attended word on the second (probe) trial, processing of that word as the probe target is slower than is the case for completely unrelated successive trials.

The very use of the word “negative” coupled with the familiar idea of priming suggests that the activation of the ignored word is pushed below baseline. This “suppression” is not problematic if the target on the subsequent probe trial is unrelated to the suppressed prime word, but it causes slowed responding when the probe target is the distractor from the preceding prime trial. Thus, Tipper (1985, 2001; see also Houghton & Tipper, 1994) has championed an account of negative priming as arising due to inhibition of the ignored word on the prime trial that results in it taking longer to reach the activation necessary to permit response production on the probe trial. This explanation fits nicely with the name of the task. Quickly, negative priming became the hallmark measure of inhibition and the task was pressed into service to explore suspected deficits in inhibitory processing in such diverse groups as schizophrenic patients (Beech, Powell, McWilliam, & Claridge, 1989; but see MacDonald, Antony, MacLeod, & Swinson, 1999) and elderly people (Hasher, Stoltzfus, Zacks, & Rypma, 1991).

Tipper (2001, p. 322) claims that “Negative priming is therefore a means of observing an inhibitory process that is assumed to be a normal component of selective attention.” The representation of the distractor on the prime trial becomes, as Tipper puts it, “associated with inhibition.” This, in turn, impairs processing of that same item when it becomes the target in the probe display. Under this view, attention selects an item both by accentuating the target and by de-accentuating the distractor(s), an idea which goes back at least to Pillsbury (1908). Houghton and Tipper (1994) present a model in which a template is created for the key feature that indicates the object that requires a response (action). Inputs that match the template are excited; those that mismatch are inhibited. Template matching is the core of the model, although the model also emphasizes suppression of distractors, with greater inhibition placed on distractors that are more likely to interfere (“reactive inhibition,” an idea that goes back at least as far as

Wundt, 1902). Tipper (2001, p. 336) summarizes a considerable body of research that he sees as consistent with such an inhibitory explanation of negative priming, concluding that "Thus far, there is little clear evidence to unequivocally discount the notion that negative priming reflects an inhibitory selection mechanism."

Although the inhibition account of negative priming has dominated, plausible non-inhibitory explanations of the phenomenon do exist. We will consider two (for more discussion, see MacDonald & Joordens, 2000; Tipper, 2001). First, Neill (Neill & Valdes, 1992; Neill & Mathis, 1998) has proposed, on the basis of Logan's (1988) instance theory of automaticity, that we routinely retrieve information from memory to assist with current processing. This retrieval may well be done automatically and unintentionally. Neill's episodic retrieval account holds that the most likely information to be retrieved is the most recent: that from the preceding trial. On ignored repetition trials, the memory check will thus retrieve a "do not respond" status for the distractor from the prime trial which conflicts with the "respond" status of the attended word on the probe trial. The resulting delay on the probe trial—negative priming—is a consequence of time spent resolving this conflict, despite the fact that the item is actually repeated.

A second alternative to inhibition as an explanation of negative priming is the feature mismatch account (Lowe, 1979; Park & Kanwisher, 1994). Like the episodic retrieval account, this is a retrieval-based explanation, the difference being that the focus of the mismatch shifts from response conflict to stimulus feature conflict. In the typical negative priming experiment, each trial has one word in one color (red) and one in another color (white), and the participant must consistently respond to one of the colors on each trial. Referring to the ignored repetition trial on the left side of Fig. 1, the word "hatchet" appears in white (do not respond) and the word "banjo" appears in red (respond) on the prime trial. On the probe trial, however, the participant must respond to the word "hatchet," which now appears in red. Thus there is a disagreement in color because the red target on the probe trial will have switched from white on the preceding prime trial. Resolving this stimulus conflict produces a slowing—negative priming.

Increasingly, these retrieval-based accounts have been gaining support, as indeed have episodic retrieval theories of priming more generally (e.g., Ratcliff & McKoon, 1988; Whittlesea & Jacoby, 1990). But is it the retrieval of stimuli, responses, or both that is crucial in eliciting negative priming? Malley and Strayer (1995) showed that negative priming occurred only for small sets of stimuli and their responses (a dozen or fewer). The effect vanished and even turned to positive priming for larger sets. Malley and Strayer did not, however, manipulate the numbers of stimuli and responses independently.

In our laboratory, Chiappe and MacLeod (1995) used a set of 10 items consisting of two instances from each of five categories. Negative priming was unaffected by a switch in task—from naming to categorization or vice versa—between the prime and probe trials. The differing numbers of responses—five in categorization vs ten in naming—did not matter. This suggests that it is the number of stimuli that is important, not the number of responses.

We are testing this conclusion further. Using four instances from each of five categories, MacLeod, Bibi, and Stamenova (ongoing) had participants name items in one block of trials (i.e., 20 item names) but categorize them in the other block (i.e., 5 category names). If the limitation on negative priming stems from the number of responses, then there should be negative priming when categorizing (5 responses) but not when naming (20 responses). If the limitation is on stimuli, then the 20 stimuli should be a sufficiently large set to eliminate negative priming regardless of the nature of the response. There was, in fact, no negative priming in this study, consistent with the set size limitation being on the stimuli, not on the responses.

Convergence on the importance of the stimuli themselves comes from two other studies conducted at the University of Toronto at Scarborough. MacLeod, Chiappe, and Fox (in press) directly tested the feature mismatch account of negative priming. Recall that, in the standard procedure, a color signal indicates which is the target word on each trial, with red always meaning respond and white always meaning ignore. Thus, the ignored item in white becomes the response-relevant item in red on critical ignored repetition trials. Could this color mismatch underlie negative priming, consistent with the feature mismatch account? MacLeod et al. replicated the standard procedure in one block (the “constant red-red” block), and observed standard negative priming for two independent sets of materials (categorically related and associatively related words). These results are shown in the left panel of Fig. 2.

In another block (the “switch red-white” block), MacLeod et al. (in press) made a seemingly small change in procedure: Participants were told to alternate between responding to the red item on one trial and the white item on the next. In this way, the ignored (white) item on the prime trial became the target (also white) on the probe trial, with no change in the stimulus. As the data in the right panel of Fig. 2 show, negative priming vanished for both sets of materials. When the ignored stimulus kept its color upon becoming the target, there was no feature mismatch and hence no basis for negative priming under the feature mismatch account. Both the episodic retrieval and the distractor inhibition accounts would predict negative priming in this situation. We note in passing that it would be interesting to extend this approach to the location version of negative priming as well.

MacDonald and Joordens (2000, Experiment 1) used a procedure that they had introduced earlier (MacDonald, Joordens, & Seergobin, 1999) in which participants have to say which of two words on each trial has the larger referent (e.g., MOUSE, DONKEY).

Interestingly, this task, which necessitates that both words be attended on each trial, produces extremely large negative priming—on the order of 100 ms instead of the usual 20 ms. MacDonald and Joordens had two types of blocks. In one, the rule was to always respond with the larger item such that, in the ignored repetition condition, ignored items moved from being smaller on the prime trial to being larger on the probe trial, causing a selection feature mismatch. In the other block, participants were to alternate between responding to the larger item and responding to the smaller item. In this case, the ignored repetition item was the smaller one on both the prime and the probe trials, constituting a selection feature match. Just as MacLeod et al. found, there was negative priming in the mismatch condition but it disappeared in the match condition. Impressively, this meant that a 100-ms effect was eliminated by removing the selection feature mismatch.

MacDonald and Joordens (2000, Experiments 2 and 3) replicated this finding using number words (e.g., which is larger: THREE or SIX?). In Experiment 3, their *pièce de résistance*, they obtained negative priming only when there was a selection feature mismatch between the trials (i.e., when the number word changed from being the smaller to the larger, or when the number word changed color). Negative priming disappeared when the repeated item was congruent on the selection feature across the prime and probe trials. Indeed, mismatch even slowed responding on attended repetition trials. In their laboratories, Park and Kanwisher (1994) and Milliken, Tipper, and Weaver (1994) have also reported negative priming only with a mismatch on the selection feature of a repeated item between prime and probe trials.

It is our contention that negative priming results from the resolution of a conflict between the selection feature of the current stimulus and that of the previous stimulus. This conflict arises because we routinely run a memory check to find information relevant to the current situation. The most likely information to turn up in that memory check is the recent information from the latest trial; it is in fact quite likely to still be in working memory, and thus readily accessible. When that information is relevant (i.e., concerns the same item) but there is disagreement on the selection dimension, this disagreement must be resolved, a process which adds to the normal processing time. Automatic memory retrieval provides the stimulus feature conflict; resolving that conflict produces interference. Under this account, there is no inhibition at all. Indeed, automatic memory retrieval is ordinarily beneficial so we would not want to suppress our (immediate) past, whether in terms of the stimulus, as we have emphasized here, or the response, as Neill and Mathis (1998) emphasize. It is only in somewhat contrived situations, such as the negative priming task, that this normal episodic retrieval works against us.

In his recent defence of the inhibition account of negative priming, Tipper (2001, p. 321) has maintained that "there is *no* firm evidence to discount inhibition models." He argues that episodic retrieval is fundamental to an inhibition account, indeed claiming that "there is no necessary conflict between inhibition and episodic accounts of negative priming" (p. 329). We see this as substantially blurring the distinction, and would argue that it is just as reasonable to conclude—in line with parsimony—that there is no firm evidence to *require* an inhibition explanation of negative priming. Memory retrieval is a systemic element of cognition; if it alone can explain negative priming, there is no need to overlay a highly flexible set of inhibitory processes of the sort advocated by Tipper (2001, p. 335).

In fact, explaining negative priming would appear to require retrieval of recent relevant information from memory, coupled with resolution of the conflict created by the current information and the retrieved information. We contend that memory is always in use, in conjunction with processing of the present, to assist with the determination of our responses and actions. So often in the world we can simply do what we just did again to perform successfully, using memory to avoid any need for problem solving (see Jacoby, 1978). We therefore rely heavily on memory. It is only when that reliance leads to conflict that we must slow down to make a decision, and this relatively infrequent cost is worth the much more frequent benefit of relying on memory. Negative priming creates a situation that emphasizes that cost. We now consider another attentional paradigm where there is a cost to looking back, and where inhibition has also been posited as the cause.

B. Inhibition of Return

To perform tasks in a visually complex environment successfully and efficiently, task-relevant objects must be quickly located and identified. Although visual search often involves eye, head, and body orientation movements, covert attentional search can increase the efficiency of the search process. To minimize repeated searching of the same location, it would be useful if a mechanism existed that biased covert attention toward novel, previously unsearched locations. To realize this bias, Posner and Cohen (1984) proposed an inhibitory attentional mechanism, stating that, "… the inhibition effect evolved to maximize sampling of the visual environment" (Posner & Cohen, 1984, p. 550). They suggested that a peripheral visual stimulus initially attracts attention to its location, but that an inhibitory mechanism then decreases processing of further information at that location. Shortly thereafter, Posner, Rafal, Choate, and Vaughan (1985) called this mechanism *inhibition of return*. No doubt because of the extensive literature that has developed regarding this phenomenon over the past two decades—but perhaps in part because the word "inhibition" is included in its name—inhibition of return has been very widely cited as evidence of a pivotal role for inhibition in attention.

Posner and Cohen (1984) derived the idea that previously attended locations are inhibited from examining the time course of the effects of uninformative spatial cues on target processing. Fig. 3 illustrates their method, which is quite typical of "standard" inhibition of return experiments. First, three outline boxes are presented in a horizontal row, with participants instructed to fixate the center box and to move only their attention, not their eyes, during the trial. Second, one of the peripheral boxes is brightened, which is assumed to reflexively draw attention to that cued location (cf. Yantis & Jonides, 1984). Third, a filled square target is presented either in the center box (60% of trials), in the cued box (10% of trials), or in the uncued box (10% of trials). Because the task is simply to detect as quickly as possible that the target has been presented, the remaining 20% of trials are catch trials without a target. Across trials, the cue and target locations are independent.

Posner and Cohen (1984) found that for brief (0, 50, and 100 ms) cue-target onset asynchronies, detection of the target was faster at the cued than at the uncued location, the intuitive pattern. Generally, the cause of this facilitation at the cued location has been attributed to an automatic capturing, or reflexive orienting, of attention by the peripheral cuing event. It might be expected that the brief facilitation would simply dissipate with time as attention moved back to the central fixation point. However, Posner and Cohen found that for cue-target onset asynchronies of 300 and 500 ms, detection was now slower at the cued location than at the uncued location. This slowing is the empirical manifestation of inhibition of return (IOR). The entire data pattern is shown in Fig. 4.

To account for IOR, competing theories have proposed inhibitory effects that function at the perceptual, attentional, and response levels of processing. At the perceptual level, it has been suggested that IOR may slow the rate at which perceptual information accumulates at the cued location (e.g., Abrams & Dobkin, 1994; Gibson & Egeth, 1994; Handy, Jha, & Mangun, 1999). Others have suggested that the effect of IOR on perceptual processing is not direct, but mediated by its influence on the attentional system. As the name of the phenomenon was intended to suggest, IOR may inhibit the attentional system from reorienting back to the cued location, resulting in either delayed or slower perceptual processing at the cued location (e.g., Rafal, Egly, & Rhodes, 1994; Reuter-Lorenz, Jha, & Rosenquist, 1996). For example, Rafal et al. (p. 295) state that IOR "… does not directly inhibit perceptual processing (at the cued location); rather it slows the reorienting of attention and this slowing compromises … detection of subsequent targets there." Reuter-Lorenz et al. found that the same variables (e.g., target modality, target intensity) that affected performance in cuing procedures also affected IOR. Given that the mechanism underlying cuing effects is generally accepted to be attentional, they argued that the mechanism underlying IOR was also likely attentional.

Despite numerous findings of IOR in detection tasks (e.g., Pratt, 1995), early failures to find IOR in discrimination tasks (e.g., Terry, Valdes, & Neill, 1994) suggested that perceptual sensitivity at the cued location was not inhibited. This led to a preference for response bias accounts over perceptual and attentional inhibition accounts. For example, Klein and Taylor (1994) proposed that IOR is due to a bias against responding to a stimulus presented at a cued location. Support came from Abrams and Dobkins (1994). Using the standard display containing two peripheral boxes, they presented a peripheral cue in one box followed by an arrow signal at fixation that directed the participant to make a saccade to one of the boxes. If IOR resulted only from perceptual inhibition at the cued location, then it should not manifest itself because interpretation of the arrow required no perceptual processing at the cued location. Abrams and Dobkins did find IOR in the central arrow condition, leading them to argue that there must be a response component underlying IOR. Furthermore, because they found even greater IOR for a condition with a peripheral signal that required perceptual processing at the cued location, they suggested that IOR contained both a perceptual and a response component.

Other research suggested that inhibitory tags can be attached not only to cued locations but also to cued objects (Tipper, Driver, & Weaver, 1991; Tipper, Weaver, Jerraut, & Burak, 1994), a system that may be more useful in dynamic real-world situations (see Klein, 1988, 2000). Regardless of the particular instantiation, however, the inhibitory response tag account seems unable to account for Maylor and Hockey's (1985) finding of IOR in a continuous target-target procedure. In this procedure, target 1 functioned as the cue for target 2, which functioned as the cue for target 3, and so on. Consequently, there were no cues to which to attach a "target absent" tag, and so IOR would not be expected according to the inhibitory tagging account.

We turn now to an account of IOR that does not rely on inhibition. Although the name IOR clearly calls for an inhibitory explanation, an attentional account does not in fact necessitate invoking inhibition. This is most obvious in the attentional momentum account proposed by our colleagues at the University of Toronto, Jay Pratt and Thomas Spalek, together with their collaborator, Frederick Bradshaw. Pratt et al. (1999, p. 732) proposed "that attention has something like momentum associated with it that allows it to be oriented to locations along the direction of orientation faster than to locations that require a change in the direction of orientation" and that attentional momentum "may best be thought of as the bias for attention to continue moving in the direction in which it most recently traveled."

Under their attentional momentum hypothesis, the cue causes an initial reflexive movement of attention to the cued location. Attention then moves back toward the central fixation cue, where the eyes remain fixated. Because attention is now oriented toward the uncued location, it is biased to move in that direction, thereby speeding responding to the uncued location and slowing responding to the cued location. Attentional momentum is thus a non-inhibitory mechanism that can explain IOR.

In a four-location IOR experiment, Pratt et al. (1999, Experiment 1) provided evidence for attentional momentum by examining target detection latencies to the cued location and to each of the three uncued locations. All were equidistant from fixation, forming a plus sign. As usual, detection latencies were slowest at the cued location. The attentional momentum account made the further prediction that because attention last moved toward the uncued location *opposite* the cued location, attention should be biased toward the opposite uncued location. As expected, latencies to the uncued location opposite the cued location were faster than latencies to either of the two uncued locations that were orthogonal to the cued location.

In prototypical IOR experiments, the attentional path is toward the uncued location and therefore attentional momentum theory produces the same primary prediction as the other theories—slower responding at the cued than at the uncued location—but without invoking inhibition. To disentangle these theories, Pratt et al. (1999, Experiments 4 and 5) used an additional cue to manipulate the orientation of the attentional path independent of the cued location. This extra cue could lead attention either further along the path away from the initially cued location (continue cue condition) or back toward the initially cued location (reverse cue condition). For the continue cue condition, they found IOR for the initially cued location and facilitation for the uncued location; for the reverse cue condition, IOR was eliminated, again supporting the attentional momentum hypothesis.

In his dissertation, Thomas Spalek (2002) has extended the attentional momentum account, linking it to the representational momentum idea of Freyd and Finke (1984) in which objects in motion are remembered as being further along the path of motion than they actually were. If these two ideas are related, then attentional momentum might be expected to have some of the same properties as representational momentum. Spalek focused on two biases in particular: left-to-right as in reading (Halpern & Kelly, 1993), and top-to-bottom as in gravity (Hubbard, 1990). His question was whether these same biases would be evident in the IOR paradigm. Using X-configured IOR displays, Spalek showed in a series of experiments that indeed both biases operate in IOR just as they do in the representational momentum studies. Moreover, his ongoing work (e.g., Spalek, Hammad, Betancourt, & Joordens, 2002) suggests that the left-to-right bias due to reading is not present—and may even be reversed—in individuals from Egypt, whose language is Arabic, which is read right-to-left. The inhibition accounts make no directionality predictions, whereas the attentional momentum account is fundamentally a directional account and readily accommodates these biases.

Inhibition of return is, therefore, another example of a phenomenon in which quite compelling inhibition-based theories were initially proposed and then widely supported; indeed, inhibition remains the dominant explanation. Again, though, as was the case with negative priming, we see in recent research the emergence of an alternative theory. Attentional momentum is based on a non-inhibitory mechanism yet seems able to account for the phenomenon. The theoretical debate, however, remains heated (see, e.g., Snyder, Schmidt, & Kingstone, 2001, for a counter-argument), and we cannot settle it here. Inhibition of return is an especially good case in point because it actually invokes inhibition as the explanatory process in the name of the phenomenon. It is our view that tasks are best named after the observable elements of the task, rather than after the theory initially proposed to explain performance of the task, a point to which we will return later.

For the present, we simply wish to note that the two attentional tasks most widely cited as requiring explanations in terms of inhibition can both be successfully explained without invoking inhibitory mechanisms. We will now more briefly consider three additional cases of attentional situations where initial inhibition accounts have been challenged.

C. Other Attention Illustrations

1. The Stroop Effect

The most venerable of all interference situations is the *Stroop task* (Stroop, 1935; see MacLeod, 1991, for a review), in which participants are required to name the color of the stimulus while ignoring its identity. This seemingly simple task turns out, in fact, to be notoriously difficult. The two basic conditions are the incongruent condition, in which the word and the color in which it is printed are incompatible (e.g., the word BLUE printed in red, say "red") and the neutral condition, in which a non-color word or letter string is colored (e.g., the word TABLE or the string XXXX printed in red, say "red"). The typical finding is that response times for incongruent stimuli are substantially slower than those for neutral stimuli, evidence that processing of the word in the incongruent condition impedes color naming.

This "Stroop interference" is often referred to in the literature as "Stroop inhibition," conflating phenomenon and explanation. In such cases, the term inhibition is used as a synonym for the term interference (Bibi, Tzelgov, & Henik, 2000; Sugg & McDonald, 1994; Tzelgov, Henik, & Berger, 1992), despite inhibition being an explanatory idea and interference being an observed data pattern. It is an interesting footnote that Stroop himself was well aware of this confusion, as the first sentence of his famous article clearly indicates: "Interference or inhibition (the terms seem to have been used almost indiscriminately) has been given a large place in experimental literature" (Stroop, 1935, p. 643).

What exactly is meant by inhibition in the Stroop task is not clear. It could be seen as indicating the failure of attention to block processing of the word because word processing is automatic (e.g., Logan, 1988; Posner & Snyder, 1975a,b). Or, it could imply an interaction: that processing of the word disrupts processing of the color (e.g., Cohen, Dunbar, & McClelland, 1990). Regardless, under an inhibition account, some representation is inhibited, either in terms of its activation or the ability to retrieve it. If a representation is required for inhibition to take place, then inhibition should be absent when no representation exists, and interference should be reduced or even eliminated. In conflict with this prediction, data collected in our laboratory by Bibi and MacLeod (2002) confirm findings reported by Monsell, Taylor, and Murphy (2001) indicating that response times for words and for pronounceable nonwords do not differ, both showing equivalent, reliable interference relative to a nonlexical neutral condition (asterisks). Because pronounceable nonwords have no representations, no inhibition should have occurred. Indeed, the fact that interference is roughly equivalent whether measured against a non-color word baseline (e.g., HORSE in red) or a nonword baseline (e.g., DRAL in red) is further evidence that the effect is not simply a function of existing representations.

It is also instructive to consider how formal models handle Stroop interference. Cohen, Dunbar, and McClelland (1990; see also Cohen, Usher, & McClelland, 1998) proposed a parallel distributed processing account of the Stroop effect according to which congruent stimuli (e.g., RED in red, say "red") result in faster responses because processing of the word dimension produces "excitatory input to the response unit." In contrast, for incongruent stimuli, processing of the word "contributes inhibition, decreasing the response unit's net input" (p. 343). According to this model, processing of the word and of the color dimensions occurs in parallel, and the influence of one dimension on the other is restricted to the response units. Thus, processing of the word does not slow processing of the color; rather, it inhibits response execution. Therefore, what Cohen et al. refer to as inhibition is a type of response competition, although realized in the model via inhibitory links.

Although the Cohen et al. (1990, 1998) models provide good fits of the Stroop data pattern, it would appear that inhibitory links are not necessary to produce such a good fit. Recently, Roelofs (in press) has presented a new model for the Stroop task. His model succeeds in accounting for most of the results that MacLeod (1991) cited as critical findings in the Stroop literature, more so than does the Cohen et al. model. Roelofs uses a variation on the WEAVER++ model of word production in which processing is based on spread of activation that allows the network to retrieve information and production rules, which enable selection of nodes. In such a model, production rules supply (among other things) the network bias that would be implemented in other models by the use of inhibition. Hence, what would appear to be the best current model for the Stroop task is an inhibition-free model.

As we have argued, the term inhibition has had several meanings, even within this one task. If inhibition simply means that one process slows another, then the term has no real theoretical value and is simply a synonym of interference. Like Stroop (1935), we see this as confusing and we would urge researchers to distinguish between interference, an empirical result, and inhibition, a possible mechanism to explain that result. The conclusion that inhibition is involved should be made after eliminating alternative accounts that can be argued to be the cause of interference. This is especially salient given the negative priming that occurs in the Stroop task (Dalrymple-Alford & Budayr, 1966), which Neill and Mathis (1998) have suggested results from automatic memory retrieval. On the basis of our review, we intended to make two points in this section: that distinguishing between interference and inhibition is important generally across paradigms, and that Stroop interference, which might appear to be a prototypical case of inhibition, need not involve inhibition at all.

2. Task Switching

To orchestrate cognition, we must use executive processes to flexibly combine or to switch between tasks, directing our attention appropriately. Over the last decade, this ability has been studied using the *task-switching paradigm* (e.g., Allport, Styles, & Hsieh, 1994). In this situation, the task changes from trial to trial either predictably (no task cue is required) or unpredictably (a cue to the task must precede each trial). An example of a predictable sequence would be switching from word reading to color naming, or the reverse, in a variant of the Stroop paradigm (e.g., Allport et al., 1994; Wylie & Allport, 2000). The main finding is that it takes longer to respond on a trial when the task switches from the previous trial than when it remains the same. This lengthened response time is referred to as the task-switching cost.

The prevalent view (e.g., Allport et al., 1994; Rogers & Monsell, 1995) is that on each trial the participant uses a task set composed of the rules or processes defining the task for that trial. In their task-set inertia hypothesis, for example, Allport et al. (1994) claimed that there was persisting suppression of competing task sets, or of competing task processing pathways, and that the switching cost stemmed from this ongoing inhibition. In line with this, Mayr and Keele (2000) had participants evaluate the stimulus along one of three dimensions (movement, orientation, or color – A, B, or C). While constantly switching between task sets, Mayr and Keele presented critical trial sequences that included C-B-A and A-B-A. Responses to the third trial in the sequence were slower if the same task set was used on the first trial in the sequence (i.e., A-B-A) compared to having a completely unrepeated task sequence (i.e., C-B-A).

According to Mayr and Keele (2000; see also Mayr, 2002), this result could be explained only by inhibition of the first task set, which had a persisting effect into the third trial of the sequence.

Mayr and Kliegl (2000) actually argue for a memory retrieval account of the task-switching cost, based on the finding that costs are greater when the task to which the switch occurs involves greater retrieval demands. It would seem that they see this retrieval operation as coordinated with inhibition. Meanwhile, Allport has moved away from an inhibition account, preferring a retrieval account. Wylie and Allport (2000, p. 231) suggest, on the basis of long-lasting interference from the switched-from task, that "a new hypothesis, based on the learned associations between stimulus representations and response representations, does very much better. This hypothesis is similar to learning and retrieval-base theories of negative priming." Essentially, the stimulus on any trial drives retrieval of responses related to that stimulus, stimulus-response connections having been built up from previous trials in which both tasks have been encountered. The more prior experience with one stimulus-response mapping, the more that mapping will dominate in retrieval (cf. "binding" in Allport & Wylie, 2000) and, if it mismatches the currently dictated response, will cause enhanced interference. Once again, memory retrieval has the potential to unseat inhibition. It is increasingly clear that just as attention strongly influences memory, memory strongly influences attention.

3. Visual Marking

Like inhibition of return, other skills may also help to narrow visual search. Watson and Humphreys (1997) demonstrated that when a subset of the distractors (the old items) in a visual search task appeared earlier than and remained visible when the rest of the distractors and the target appeared (the new items), search time through the new items was unaffected by the presence of the old items. Yet the preview of the old items was too brief to have permitted extensive search of them. It was as if the second part of the display received priority for search. Watson and Humphreys argued that this *visual marking* of the old items—a *preview effect*—was accomplished via top-down inhibition based on a "template" that operates across the entire visual field, preventing the old items from competing for selection (compare to Houghton & Tipper, 1994). Subsequent studies have replicated and extended the basic phenomenon (e.g., Olivers & Humphreys, 2002; Watson & Humphreys, 2000), and have dissociated it from an inhibition of return mechanism that is more sequential than simultaneous (Olivers, Humphreys, Heinke, & Cooper, 2002).

Recently, Donk and Theeuwes (2001) have shown that without luminance onsets for the new items, the preview effect does not occur. Across their experiments, by varying the relative luminance of the items and the background, they had either the old items, the new items, or neither stand out from the background. Only when the new items stood out did they obtain the visual marking effect. There is nothing in the inhibition account that should make inhibition contingent on abrupt onsets of the new items—indeed, Olivers et al. (2002) explicitly claim that the inhibitory mechanism is in addition to any effect of onset—so Donk and Theeuwes argued against the inhibition account, maintaining that the visual marking effect is in fact the result of abrupt onsets, which provide clear discriminative cues for the new items.

The grouping explanation put forth by Humphreys, Watson, and Jolicoeur (2002) has been couched in terms of inhibition but could, we believe, just as readily be seen as consistent with an abrupt onset account. This is a quite engaging phenomenon, and the debate about how to explain it will continue. We simply note that the evidence for an inhibition account is not conclusive, and that there is a viable alternative in the well-established abrupt onset effect (see Yantis & Jonides, 1984).

IV. The Memory Case Studies

A. Directed Forgetting

Our second set of case studies is taken from the domain of memory. Consider the perennial observation that the successful use of memory requires not only remembering but also forgetting. As Ribot (1882, p. 61) said, "Forgetfulness, except in certain cases, is not a disease of memory, but a condition of its health and life." We must update our memories so that no longer relevant information (e.g., an old address, the name of a former significant other) is not mistakenly retrieved. Forgetting is desirable, and the idea that it can be usefully controlled has gained favor over recent decades. This situation seems especially amenable to an inhibition account of memory—and indeed such an account has been invoked. The paradigm most often used to simulate this situation in the laboratory is called *directed forgetting*, where the participant is instructed to forget some recently acquired information, typically in a list learning procedure.

There are two ways to implement these instructions: Cues are presented either immediately following each item (the item method; e.g., MacLeod, 1975) or only at the middle and end of the list (the list method; e.g., Elmes, Adams, & Roediger, 1970). Fig. 5 illustrates the two study procedures. Subsequent attempts to retrieve both the to-be-remembered (R) and the to-be-forgotten (F) items consistently reveal an advantage of R items over F items. This difference—the directed forgetting effect—has been the subject of considerable study over the past four decades (see MacLeod, 1998; Golding, 1998, for reviews).

Directed forgetting research began in earnest with a study by Muther (1965). Only a couple of years later, the inhibition account first appeared. Weiner (1968; Weiner & Reed, 1969) suggested that the F items were inhibited from being retrieved, providing what he saw as a memory-based analog to repression. This inhibition of F items served to reduce their interference with the processing of R items. But early accounts of directed forgetting quickly came to favor set differentiation (differential tagging of R and F items) and selective rehearsal (rehearsing mainly R items) as explanations (e.g., Bjork, 1970; Bjork, LaBerge, & Legrand, 1968), and the inhibition explanation was largely mothballed for about 15 years.

The return of the inhibition account of directed forgetting was championed by Bjork, Geiselman, and their colleagues (e.g., Bjork & Geiselman, 1978; Geiselman, Bjork & Fishman, 1983). Originally advocates of selective rehearsal accounts of directed forgetting, but clearly influenced by early repression theories, both Geiselman and Bjork progressively moved toward a retrieval inhibition explanation through the 1980s (see MacLeod, 1998, for a review of this switch). Initially, this account was applied to both the item and list methods, as was the selective rehearsal account before it. But then, because he found that a final free recall test showed no directed forgetting after a recognition test had been administered, Bjork (1989) suggested that different mechanisms could underlie the two methods. The idea was that selective rehearsal provides the best account of item method directed forgetting, but that retrieval inhibition offers the best account of list method directed forgetting. Retrieval inhibition would be lifted in a recognition test by presentation of an F item, explaining the absence of directed forgetting on a recognition test under the list method. By manipulating study method, Basden, Basden, and Gargano (1993; for a review, see Basden & Basden, 1998) provided further empirical support for this "two methods, two explanations" view. As a result, the most widely subscribed position at present is that there are separate mechanisms underlying list and item method directed forgetting (see MacLeod, 1998).

Under the item method, participants fail to adequately encode the F items because they terminate rehearsal at the onset of the F cue. As a consequence, F items receive less rehearsal than R items, accounting for the better recall and recognition of R items compared to F items. Thus, the effect is due to selective rehearsal at encoding.[4] In contrast, under the list method, in which a forget cue is presented part way through the list and a remember cue at the end of a list, the participant does not know that the F items are in fact to be forgotten until they have already been encoded and rehearsed, so selective rehearsal would appear not to be possible. Instead, the F items are assumed to be inhibited subsequent to encoding, and this inhibition diminishes retrieval at the time of recall.

The most frequently cited piece of evidence for inhibition in the list method comes from the failure to find a directed forgetting effect on a recognition test (e.g., Geiselman & Bagheri, 1985). Under the inhibition view, the ability to recognize items that could not be recalled indicates that they were inaccessible during recall, rather than not learned. A simple re-exposure to the inhibited items is enough to release the inhibition and produce recognition at comparable rates to never forgotten (i.e., R) items. This release does not occur in item method directed forgetting, indicating that the F items are not inhibited there but are simply not very well learned in the first place, a result of diminished rehearsal and encoding of the F items. MacLeod (1999) demonstrated the complete pattern in one study, the data of which are displayed in Fig. 6.

Although the evidence in support of inhibition may seem persuasive, by now the reader will not be shocked to learn that we are not persuaded. Rather, we have been gathering evidence that suggests that selective rehearsal may, after all, provide an adequate inhibition-free account of directed forgetting findings under both methods. This would be much more parsimonious, eliminating the need for two mechanisms to explain the two versions of this one task. In the rest of this section, we will briefly sketch out two recent series of experiments in our laboratory that suggest that rehearsal does in fact play a crucial role in list method directing forgetting.

In the first series—Sheard, Dodd, Wilson, and MacLeod (2002)—we explored the situation that Basden and Basden (1998; see also Gilliland, McLaughlin, Wright, Basden, & Basden, 1996, Experiment 2) have referred to as the "warning effect" in list method directed forgetting. When, prior to a delay, Basden and Basden informed participants that both R and F words were to be recalled after the delay (the *delay – warning* condition), directed forgetting was eliminated. In contrast, providing a delay without a prior warning (the *delay – no warning* condition) yielded a normal directed forgetting effect, like that in the standard situation without delay (the *no delay* condition). They explained their warning effect findings in terms of retrieval inhibition: With or without a delay, at recall, participants adopt a retrieval strategy that favors the R items, and so the F items are inaccessible or inhibited. But, if a warning is given prior to a delay, they suggest that there is time to switch to a retrieval strategy that allows recall of both R and F words. Changing retrieval strategy presumably takes some time, otherwise participants would switch strategy in the standard condition when the usual instruction to recall all words is given immediately prior to the recall test. Why such a change would require minutes, not seconds, is not clear.

We do not see Basden and Basden's (1998) results as demanding an inhibition account; indeed, we see a selective rehearsal account as accommodating the warning effect findings quite comfortably. Assume that, during a delay with a prior warning, participants might actually selectively rehearse the F words, realizing that these are the words that they are most likely to have trouble recalling. This shift to rehearsing the F words would be detrimental to the R words, the result being a decrease in recall of R, an increase in recall of F, and hence an overall reduction in the directed forgetting effect. Furthermore, although inconsistent with Basden and Basden's results, during a delay with no prior warning, we would expect participants to selectively rehearse the R words, anticipating that only these words would be tested (as they had been told at the outset). This will be detrimental to rehearsal of the F words, therefore resulting in a larger directed forgetting effect than in the usual no-delay situation. Although Basden and Basden did not find an increased directed forgetting effect, this may have been due to their use of related words that caused less forgetting of the F words (cf. Golding, Long & MacLeod, 1994).

To investigate these predictions from a selective rehearsal perspective, we first replicated Basden and Basden's (1998) pattern of results. We found a typical directed forgetting effect in the standard *no delay* condition and slightly reduced directed forgetting effect in the *delay – warning* condition. Further, as we had predicted, we found an enhanced directed forgetting effect in the *delay – no warning* condition. To determine whether rehearsal played a role in the directed forgetting effect, we performed a median split based on overall recall performance (R+F). We anticipated that high-memory participants likely would have rehearsed considerably more than low-memory participants.

An interesting pattern of results emerged. Consider first the low-memory group, shown in the left panel of Fig. 7. They showed equivalent directed forgetting in the *delay – warning* condition and in the *delay – no warning* condition. Not surprisingly, total recall performance in both of these delay groups was reduced relative to the *no delay* condition, but the reduction derived only from reduced recall of R words. The implication is that the low-memory participants were not selectively rehearsing any words (R or F) during the delay.

In contrast, the high-memory group (shown in the right panel of Fig. 7) demonstrated a modest directed forgetting effect in the *no delay* condition, a substantially increased effect in the *delay – no warning* condition, and a reduced effect in the *delay – warning* condition. We see this pattern as entirely consistent with these participants engaging in differential rehearsal. In the *delay – no warning* condition, R words were selectively rehearsed, resulting in an actual increase in R word recall and a decrease in F word recall, and a consequent increase in the directed forgetting effect, relative to the *no delay* group. In the *delay – warning* condition, diverting more rehearsal to the F words resulted in a smaller loss in F words but led to a decrease in recall of R words, producing a diminished overall directed forgetting effect relative to the *no delay* condition. In our view, high-memory participants clearly tailored their rehearsal as a function of the warning condition. Unlike the selective rehearsal account, the inhibition view would not predict directed forgetting differences between low-memory and high-memory individuals.

In a follow-up experiment, we set out to manipulate rehearsal directly by either increasing or decreasing opportunity and motivation to rehearse during the delay. To reduce the likelihood of rehearsal, we filled the delay with an effortful task; to increase the likelihood of rehearsal, we announced, prior to the delay, that there would be a financial incentive to recall as many words as possible. We predicted that the pattern of results for participants with a filled delay—and therefore discouraged from rehearsing—would match those of our low-memory group, and that the pattern of results for participants with a financial incentive—and therefore encouraged to rehearse—would match those of our high-memory group. The findings supported these predictions. Taken together, the experiments in this series suggest that selective rehearsal makes an important contribution to list method directed forgetting under conditions of delayed recall; it remains to be determined whether this is also the case in immediate recall.

In a second series of experiments ongoing in our laboratory, Sheard and MacLeod (2002) have taken a different tack but have been led to the same conclusion that selective rehearsal underlies list method directed forgetting. In an extended set of serial position analyses, we have found that differences between F and R items in list method directed forgetting stem not from poorer *overall* recall of F items, but from impaired recall of only portions of the F sublist. Using the standard list method comparison—a within-subject comparison of the F (first) sublist to the R (second) sublist—we have observed diminished primacy and recency for the F sublist relative to the R sublist. The asymptotic positions were quite equivalent. Fig. 8 shows the serial position pattern.

This finding fits with the rehearsal perspective because the F sublist is presented before the R sublist, so that the F sublist should suffer retroactive interference that should particularly minimize recency. However, it is less intuitive from an inhibition perspective, which has always been cast as if retrieval of the entire F sublist is inhibited (see, e.g., Basden & Basden, 1998). Of course, the "reactive inhibition" idea (Houghton & Tipper, 1994; Wundt, 1902; see the "Negative Priming" section) could be used to argue that it is these beginning and end positions that most require inhibition, but this argument amounts to claiming that inhibition is selective in the same way as rehearsal.

That, however, is not the end of the serial position story. In further experiments, Sheard and MacLeod (2002) have used the more appropriate (but less standard in the literature) comparison between the first sublist from a forget-remember (F-R) group and the first sublist from a remember-remember (R-R) group. This eliminates the usual confound of the F sublist always preceding the R sublist. The serial position data in this comparison show considerably more primacy for the first sublist in the R-R group than in the F-R group, so the directed forgetting effect remains specific to certain serial positions. But we then added a new R-R group given instructions (between the sublists) to stop rehearsing the first R sublist, hoping to mimic what the F group presumably does when they are instructed to forget. We assumed that this "stop rehearsal" R-R group would be more analogous to the F-R group if rehearsal was the crucial mechanism operating. Performance in the F-R and stop rehearsal R-R groups was almost the same across the serial position curve: Both showed modest primacy and no recency, and there was no reliable overall directed forgetting effect (see Fig. 9). Because the inhibition account makes no prediction concerning such an instruction not to rehearse, this result is decidedly more consistent with a selective rehearsal account.

Retrieval inhibition is still the dominant explanation of list method directed forgetting (see MacLeod, 1998, for a review). What we have tried to demonstrate in this section is that our recent work reveals a likely role for selective rehearsal even in the list method. We hasten to note that we are not alone in this initiative (see, e.g., Kimball & Metcalfe, 2001) to provide a common selective rehearsal account for the list and item methods. This approach is certainly more parsimonious than having two separate mechanisms for two such similar procedures. The flexibility of the inhibition account makes it rather difficult to put to a stringent direct test, but we believe that the convergence across the lines of research that we have described provides support for a general selective rehearsal account of directed forgetting. Once again, routine memory operations can handle the data without augmentation by an inhibitory mechanism.[5]

B. Retrieval-Induced Forgetting

In the memory domain, directed forgetting is probably the most visible and longstanding phenomenon where inhibition has been invoked as explanatory. But there certainly are others. Another recent example is a paradoxical situation in which the act of remembering some material disrupts the retrieval of other, related material. Labelled *retrieval-induced forgetting*, this phenomenon has been explored by Anderson and colleagues (e.g., Anderson, Bjork, & Bjork, 1994; Anderson, Bjork, & Bjork, 2000; Anderson, Green, & McCulloch, 2000) and others (e.g., M. D. MacLeod & Macrae, 2001; Williams & Zacks, 2001). Although the term retrieval-induced forgetting is relatively new, it is worth noting that related findings had been reported earlier (e.g., Blaxton & Neely, 1983; Roediger & Schmidt, 1980; Smith, 1971).

Anderson et al. (1994) first observed retrieval-induced forgetting using lists of words consisting of category-exemplar pairs. Their method is illustrated, using their Experiment 1, in Fig. 10. Typically, 6 exemplars e.g., *Fruit-Orange*, *Fruit-Nectarine*, etc.) were used in each of 8 categories (e.g., *Fruit*, *Drink*, etc.). Four of the categories contained only strong exemplars and four contained only weak exemplars. Participants were instructed to learn the pairs for a later memory test. After the study session, there was a practice session in which participants were cued repeatedly (e.g., *Fruit-Or*___) for half of the words from half of each of the strong-exemplar and weak-exemplar categories. At test, participants were provided with category cues and asked to recall all of the studied words.

The results from their Experiment 1 are summarized in Fig. 11. Not surprisingly, recall was best for the practiced pairs from practiced categories (P-P). Interestingly, though, recall was poorer for unpracticed items from practiced categories (P-U) than for (unpracticed) items from entirely unpracticed categories (U-U). Anderson et al. (1994) argued that this detriment was indicative of inhibitory processes that suppress related material when practiced material is correctly recalled. Under their account, during the practice session, studied words compete with each other while a search for the correct stem completion is ongoing. This competition necessitates a suppression/inhibition of competing words, which in turn makes them less accessible at a later time. More specifically, though, they reported that retrieval impairment occurred for strong categorical exemplars (e.g., *Fruit-Orange*) but not for weak categorical exemplars (e.g., *Tree-Hickory*). They hypothesized that strong categorical exemplars are more likely to interfere during retrieval practice due to their greater associative strength, which causes them to require more inhibition. Weak categorical exemplars are less likely to interfere and may not need to be inhibited during practice. [Once again, this idea is similar to the idea of "reactive inhibition," where inhibition is greater to the extent that a distractor might be expected to intrude.] This was the first piece of evidence that led them to an inhibition account.

The second piece of evidence that fit with an inhibition account had to do with the nature of the final retrieval cue, and is referred to as the cue-independent effect. To understand this, we turn to a study by Anderson and Spellman (1995; see also Anderson & Green, 2001). Because members of the same category had to be recalled together, it could be argued that the practiced exemplars interfere with the unpracticed exemplars within a category, which clearly cannot occur across categories. To demonstrate that retrieval-induced forgetting is due to inhibition, not simply interference at recall, Anderson and Spellman used different cues on the final test. To illustrate, participants might learn *Green-Emerald*, *Green-Lettuce*, *Soups-Chicken*, and *Soups-Mushroom* during the study phase. Notice that *Mushroom* and *Lettuce* both belong to the shared category *Vegetables*, a category not learned during study. They would then practice *Green-Emerald* in the practice phase. This would lead to the inhibition of *Green-Lettuce* (because *Emerald* and *Lettuce* are both *Green*) as well as *Soups-Mushroom* (because *Mushroom* and *Lettuce* are both *Vegetables*) on a later recall test. Moreover, relative to an unrelated control condition, both *Lettuce* and *Mushroom* would be impaired when the independent cue *Vegetable* was used as a cue on another recall test. Anderson and Spellman saw this as evidence that the items were truly inhibited in memory, and not just interfered with at test.

But all is not well in the land of inhibition. More recently, Williams and Zacks (2001) attempted to replicate the Anderson et al. (1994) and Anderson and Spellman (1995) studies, homing in on both of these linchpins of the inhibition account. Put simply, although they readily replicated retrieval-induced forgetting itself in their experiments, they could not replicate either the category strength effect or the cue-independent effect. These were the two legs upon which the inhibition explanation stood. On this basis, Williams and Zacks argued that the inhibition account of retrieval-induced forgetting was seriously undermined. They preferred an account in terms of retrieval interference, with practice exerting its influence not at the time of practice but at the time of retrieval. Once again, memory retrieval plays the key role.

Continuing research on retrieval-induced forgetting has demonstrated boundary conditions on the effect (Anderson, Bjork, & Bjork, 2000; Anderson & McCulloch, 1999; Butler, Williams, Zacks, & Maki, 2001). As well, a number of studies have provided evidence for greater generality of the effect, extending it to the realms of social cognition (e.g., M. D. MacLeod & Macrae, 2001; Macrae & M. D. MacLeod, 1999), eyewitness memory (e.g. Shaw, Bjork, & Handal, 1995), and perception (e.g., Ciranni & Shimamura, 1999). In all of these, the prevailing explanation for the effect derives from the one suggested by Anderson (Anderson et al., 1994; Anderson & Spellman, 1995), albeit expressed in more general terms: Retrieving a studied item during practice is now thought to suppress/inhibit other studied items, thus accounting for the later reduction in recall of these items relative to items from unpracticed sets.

As it happens, there is an older phenomenon that appears to be closely related to retrieval-induced forgetting (a fact which Anderson et al., 1994, recognized). The *part-list cuing effect* grew out of the work of Norman Slamecka (e.g., Slamecka, 1968, 1969), a colleague at the University of Toronto for most of his career. Here, after learning a list at study, a few of the studied items are presented at retrieval ostensibly to “aid” recall. Yet presentation of this subset actually reduces the proportion of correctly recalled words from the rest of the list, relative to not presenting this subset (e.g., Todres & Watkins, 1981; Basden, Basden, & Galloway, 1977).

Researchers have gone on to examine the interfering effects—as well as those conditions under which the effects can be facilitating—of presenting a subset of studied words as cues during recall (e.g., Penney, 1988; Roediger, 1974; Sloman, Bower, & Rohrer, 1991).

A full review of the part-list cuing literature is beyond the scope of this chapter, but this effect deserves mention because it, too, was initially accounted for in terms of inhibitory processes. Presenting the "cue" list was seen as strengthening memory of cued items and blocking (inhibiting) the remainder of the studied items: "In other words, cuing may facilitate category recall but usually inhibits instance recall" (Basden et al., 1977, p. 100). Part-list cuing studies have even been conducted using category cues in a manner similar to that used in retrieval-induced forgetting studies.

Basden et al. (1977; see also Basden & Basden, 1995) specifically tested the inhibition explanation of part-list cuing. They showed that extra-list cues (i.e., cues not actually studied) did not reduce recall, and that a final free recall test (without cues) showed no residual impact of the part-list cues having been presented on the prior recall test. They saw the inhibition account as predicting a larger part-list cuing effect for strong than for weak items, but did not obtain this result, coinciding with the Williams and Zacks (2001) finding for retrieval-induced forgetting. Basden et al. (1977) concluded that inhibition was an inadequate account of the interference due to part-list cuing. Instead, they put forth a retrieval strategy disruption account: "editing cue words from recall disrupts that recall, perhaps by forcing a recall order inconsistent with intracategory organization" (p. 107), an account which they have continued to support (Basden & Basden, 1995). Though the plausibility of this strategy disruption hypothesis has been debated (e.g., Peynircioglu, 1989), this account has endured and is now considered a viable alternative to the inhibition view. Indeed, the retrieval interference account offered by Williams and Zacks (2001) for retrieval-induced forgetting would appear to be a direct descendent.

Part-list cuing can be accounted for without inhibitory processes, which raises the possibility that retrieval-induced forgetting can be accounted for in the same way. It could be that the practice session, which requires participants to recall a subset of words, disrupts the original organization of studied words in practiced categories, making the unpracticed words from the practiced categories more difficult to recall. Words from the unpracticed categories, however, are easier to recall because the organization of these items has not been disrupted by the practice session.

A number of findings from the literature can be aligned with this view. Although Anderson et al. (1994) observed a retrieval-induced forgetting effect up to 20 minutes after the practice session, the effect had dissipated by 24 hours after the practice session (M. D. MacLeod & Macrae, 2001). This could mean that once participants are far enough removed from the disruptive practice session they are able to return to their original retrieval strategies or organization. Anderson and McCulloch (1999) reported that making multiple connections between list items at study created an immunity to retrieval-induced forgetting, reminiscent of a similar finding in directed forgetting (Golding et al., 1994). Relatedly, Smith and Hunt (2000) demonstrated that retrieval-induced forgetting could be reduced when individuals were encouraged to engage in further “distinctive” processing for each presented word. Under the retrieval strategy disruption hypothesis, even if the practice session disrupts the organization of some items in memory, the greater durability afforded by multiple or distinctive representations can ward off the detrimental effect of this disruption.

Anderson and McCulloch (1999) acknowledged the strategy disruption account but did not see it as a viable explanation of the existing retrieval-induced forgetting data. Currently, no study exists in the literature that explicitly tests the strategy disruption hypothesis as it may relate to retrieval-induced forgetting. This leads us to conclude that dismissal of retrieval strategy disruption as an alternative account for retrieval-induced forgetting effects would be premature. How we orchestrate retrieval of information from memory is a powerful influence on our likelihood of success, so disruption of a retrieval scheme could be very damaging. Despite the provocative demonstrations of Anderson and his colleagues, the need to invoke an inhibition account in this setting remains to be established.

C. Other Memory Illustrations

1. Aging and Memory

Another University of Toronto colleague, Lynn Hasher, with her colleague, Rose Zacks, has championed an inhibition-based account of the cognitive decline seen in aging, particularly in memory. Beginning with Hasher and Zacks (1988), they have argued that cognitive control involves the tandem processes of excitation and inhibition, with a loss in inhibitory control being the primary factor underlying the change with age. Zacks and Hasher (1997) and Hasher, Zacks, and May (1999) maintain that there are three inhibitory processes that diminish with age: (1) processes that control what information enters working memory, (2) processes that control the unloading or deletion of no longer needed information from working memory, and (3) processes that reduce the probability of incorrect but possibly relevant responses being made.

We do not dispute the cognitive decline data, but we do question their interpretation in terms of inhibition. That older adults are more susceptible to distraction from information not relevant to their current task is an empirical observation, one that we prefer to call, more neutrally, a performance cost. Older people suffer greater interference from to-be-ignored text surrounding to-be attended text (Carlson, Hasher, Connelly, & Zacks, 1995). They also are more likely to remember information that they need not remember (Hasher, Quig, & May, 1997), or even that they are explicitly instructed to forget (Zacks, Radvansky, & Hasher, 1996). Better memory for to-be-ignored information could be due to the failure to inhibit that information. But do we have to appeal to inhibition to account for these cognitive effects of aging?

Older people could fail to prioritize processing of relevant information either by failing to inhibit irrelevant information or by failing to promote or enhance relevant information. Both mechanisms could explain inefficient selection. We suggest that the greater distractor interference suffered by older people does not result from them failing to inhibit the irrelevant but from them failing to enhance the relevant. We believe that this is a less cumbersome account, obviating the need for inhibition or its failure.[6]

In a related vein, using the process dissociation procedure (Jacoby, 1991), Jacoby, Debner, and Hay (2001) have argued that the greater interference often seen in older adults is "caused by a deficit in recollection rather than a deficit in the ability to inhibit a preponderant response" (p. 697). Essentially, as recollection worsens with age, a habitual response is made because recollection cannot be used as successfully to countermand that response at the time of test. In this situation, then, a failure in episodic memory results in the expression of a response that would otherwise be avoided. [Indeed, it may be that older individuals come to rely on memory of recent or habitual events more, given their knowledge that their memory is poorer than it once was, which presents them with more responses that require countermanding.] Once again, episodic retrieval and the resolution of response conflict would appear to be involved, without need for any inhibitory process(es) at all.

2. Lexical Decision

We will consider just two more memory-related instances where inhibition has been proposed. Both occur in the *lexical decision task*, the classic semantic memory task, where the participant must determine whether each string of letters is or is not a word. Since the pioneering work of Meyer and Schvaneveldt (1976), this has become, without question, one of the most frequently employed word identification tasks of the past 30 years. Although the early work using this paradigm emphasized the benefits of priming—faster responding to a word following a related word—recent explanations have increasingly added inhibitory components as well.

In the first instance, Ratcliff and McKoon (1995) demonstrated what they referred to as nonword prime inhibition, in which the response to the target word of a prime-target pair was slower when preceded by a nonword prime than when preceded by a word prime. McNamara (1994) failed to obtain this effect. Zeelenberg, Pecher, de Kok, and Raaijmakers (1998) suggested that whether this effect was obtained depended on the type of instruction: Instructions that called attention to prime-target relatedness (e.g., Ratcliff & McKoon) might produce the effect, whereas instructions that did not mention this possibility (e.g., McNamara) might not. This is precisely the pattern that Zeelenberg et al. observed when they manipulated instructions.

What is particularly interesting to us about the Zeelenberg et al. (1998) study is that rather than explaining the effect in terms of nonword prime inhibition, they offered a compelling alternative. They suggested that participants made a covert lexical decision response to the prime, although no overt response was required. The consequence was that the response mismatched between a nonword prime and a word target but matched for a word prime followed by a word target. Perhaps, they reasoned, the cost associated with a nonword prime did not involve inhibition but rather the resolution of the mismatch. That calling attention to the relation between prime and target increased the effect is entirely consistent with this explanation. Once again, episodic retrieval and the resolution of response conflict provide a plausible account of an empirical phenomenon previously seen as evidence of inhibition.

The second instance involves an inhibitory idea that has its roots in Ribot (1889): center-surround inhibition. Ribot had suggested that when we excite one representation we simultaneously inhibit potentially competing ones. Dagenbach, Carr, and Barnhardt (1990) suggested that, when an individual tries but fails to extract the meaning from a briefly presented masked prime word, there should be positive repetition priming for that word but negative semantic priming for a related word. The idea is that in the case of failed extraction of meaning for the masked prime word, the word itself receives small semantic activation but related words are inhibited: the center (the word itself) is activated but the surround (related words) is inhibited. Dagenbach et al. reported data thoroughly consistent with this account.

Recently, Kahan (2000) has challenged this interpretation of the phenomenon. His theoretical position is called retrospective prime clarification and rests upon the idea that when identification of the prime has just failed and the target then appears, we are compelled to resolve, or clarify, the prime before handling the target. It is memory retrieval, not inhibition, that produces the "center-surround" type of data pattern. Kahan varied the proportion of related prime-target pairs, a manipulation that he reasoned should be influential only if his retrospective clarification idea was correct, and found that this indeed did have a powerful influence. In likening his account to the episodic retrieval account of negative priming proposed by Neill (e.g., Neill & Mathis, 1998), he clearly allied himself with the memory retrieval and conflict resolution account we have been advocating in this chapter.

V. The "Big Picture"

A. The Concept of Inhibition

> "Running through the history of 'inhibition,' as with some other key concepts in science, such as 'force' in mechanics, was an ambivalence amounting to a philosophical problem. The word referred to a causal process or to a functional relationship. Both usages were common. Sometimes scientists sought to understand inhibition as a specific physical mechanism. At other times, they used the word to describe the function of particular nerves or parts of the brain. On yet other occasions, the word characterized relations within the mind or between the brain and the mind." (Smith, 1992, p. 13).

Our presentation of several case studies in inhibition has necessarily been limited even with respect to the evidence for the tasks and phenomena that we did discuss; space constraints have meant that we have had to leave out a great many more possible cases altogether. Nevertheless, across these examples, we have seen several different senses of and nuances of inhibition. As we come to the close of the chapter, we wish to characterize what has been meant by inhibition more explicitly, and then to make our own theoretical position more concrete as well. We will first indicate how attention and memory theorists have viewed inhibition.

In the domain of attention, Rafal and Henik (1994) have distinguished three inhibitory processes: inhibition of responding to signals at unattended locations, endogenous inhibition of reflexes, and reflexive inhibition of the detection of subsequent signals. In the domain of memory, as previously outlined, Hasher and Zacks (1988) have also distinguished three inhibitory processes: control of what information enters working memory, control of the unloading or deletion of information from working memory, and prevention of incorrect but possibly relevant responses from being made. More broadly, Nigg (2000) has suggested three kinds of inhibition: executive inhibition, automatic inhibition of attention, and motivational inhibition. [We will not discuss Nigg's third category, which has more to do with the clinical domain.] His "executive inhibition" includes the control of inhibition arising from competition, the suppression of irrelevant information, the suppression of highly likely responses, and the suppression of reflexive saccades. The first three of these are quite analogous to those of Hasher and Zacks. Nigg's "automatic inhibition of attention" includes attentional suppression of recently examined stimuli and the suppression of unattended information while attention is directed elsewhere. These two and the last one listed under "executive inhibition" closely resemble those of Rafal and Henik.

It is clear, then, that there is some consensus on the conceptual components of inhibition in cognition, and that there are also quite a few of these components, harking back to the three senses—suppression, restraint, and blocking—laid out by English and English (1958), and described at the outset of this chapter. It is often difficult to ascertain which one or more of these meanings is intended in existing inhibition-based accounts of cognitive processing. Unlike the meaning of inhibition in the nervous system, the meaning in the mind is much more diffuse. As Breese (1899, p. 14) put it over a century ago: "Inhibition is a term which has been used to designate all kinds of mental conflict, hesitation and arrest."

B. The Problem of Terminology

When we began working on this chapter, we wanted to illustrate the circularity problem with labelling any negative deviation from baseline as inhibition, and then taking this negative deviation as *de facto* evidence for inhibition. We had planned to use *interference* as the label for the empirical finding of below-baseline performance, and *inhibition* as the term for a particular theoretical account of that interference. We wanted to make very clear the point that *interference is not inhibition*. We have come to realize, however, that the term interference also has some degree of theoretical baggage, implying how a negative deviation from baseline occurs.

To describe negative and positive deviations from baseline, we now prefer the terms cost and benefit (Jonides & Mack, 1984; Posner & Snyder, 1975a,b).[7] A *cost* can be defined as a performance decrement relative to some baseline; a *benefit* can be defined as a performance increment relative to some baseline. If, as cognitive psychologists, we could agree to use these as the non-loaded empirical terms, then we could go on to theorize about what mental processes underlie these costs and benefits. Terms such as interference and inhibition would then be seen as theoretical terms at different levels of explanation. A performance cost might be due to interference, which in turn might involve a process or processes of inhibition—although we would not take this second step. A principal advantage of this scheme would be the avoidance of the reflexive equation of inhibition with cost (or interference).

C. An Inhibition-Free Explanation

> "Many of these inhibitory mechanisms have been suggested by, and based on, metaphors of inhibition that have come to cognitive psychology through the neural sciences. Unlike in the neural sciences, however, where inhibitory mechanisms can be observed in the hardware, in cognitive models inhibition must be inferred on the basis of overt behavior. As such, there is a danger of circularity whereby investigators attribute interference effects to inhibition and subsequently define inhibition on the basis of behavioral interference. For this reason, the terms inhibition and interference are often confused in the literature" (Klein & Taylor, 1994, p. 146)

The variations on inhibition that currently exist are rather like additional free parameters in a model: They certainly make it easier to fit the data, but they are not the preferred way to accomplish the goal. We believe that in most cases where inhibitory mechanisms have been offered to explain cognitive performance, non-inhibitory mechanisms can accomplish the same goal, without needing to summon reinforcements in the form of inhibition. We have emphasized two such mechanisms—automatic memory retrieval and conflict resolution—that we now wish to consider in greater depth. We should note that these do not originate with us, but have been successfully applied by others in explaining performance in a variety of cognitive tasks, including some of those described here. Our most direct intellectual debts are to Logan (1988; 2002) and Neill (e.g., Neill & Mathis, 1998).

Logan (1988; 2002) has proposed that automaticity results when the algorithmic processes required to perform a task lose the race against memory "instances" laid down by previous performances of the task. Each time the task is performed, relevant memory instances are recovered to assist with performance, so the probability of an instance beating the algorithm increases with each performance of the task until a memory instance virtually always beats the algorithm. Consistent with this view, Huettel and Lockhead (1999) have shown that sequence effects are very powerful in individual-trial tasks, with the most recent trial exerting a very strong influence on the current trial, whether in the form of a cost or a benefit. It is really quite intuitive that we should look back for help from recent experience, and the evidence is strongly in accord with this intuition. Very often, what we are doing now involves a good deal of what we were doing a moment ago, so routinely querying memory about the recent past can be most helpful in avoiding the need to re-analyze our task and re-compute our responses. Jacoby (1978) and Anderson and Milson (1989) have made this point nicely. In particular, routine, possibly automatic, retrieval reduces the need for frequent decisions, and decision making is perhaps the most demanding of cognitive operations (cf. Posner & Boies, 1971).

Cognitive psychologists are, however, expert at creating situations where the recent past (or even the irrelevant present) conflicts with the present. A great deal has been learned about the normal operation of cognition from performance costs; in fact, we would argue that situations involving performance costs are among our most useful cognitive tools. When the past conflicts with the present, we must resolve that conflict before we can respond, or risk making an error. Automaticity, habit, familiarity—related concepts that recognize the powerful influence of the past—are extremely difficult to deny. Indeed, Anderson and Milson (1989) have argued elegantly that memory is tuned to the statistical analysis of the past, with a particularly heavy weight assigned to the very recent past. When our ongoing processing turns up two paths that we might follow, we must choose. It is interesting, in this regard, that in their excellent book on the subject of inhibition, Diamond et al. (1963) characterized inhibition as what the nervous system does, and choice as the behavioral analog: The title of the book is *Inhibition and choice*. When memory points to the same path that our ongoing analysis points to, there is no conflict and no need for choice; when they diverge, then choice—a process that takes considerable time and effort—becomes essential to resolve conflict.

At the risk of redundancy, our candidate to replace the suppression, restraint, or blocking that constitute inhibition in cognitive theory is a combination of routine memory retrieval coupled with choosing between two (or more) routes when there is conflict. This second stage has often been referred to as "response competition," though "conflict resolution" (without resort to inhibition) might better capture our intended meaning. Memory retrieval is usually helpful and will speed performance relative to an entirely new analysis (see Jacoby, 1978). When, in a minority of situations, retrieval is not helpful, it still occurs, but now we are forced to choose—to resolve the conflict between memory and the present—and this choice adds to our processing time and may even lead to errors. The result is a performance cost. We would argue that other memory processes also play a role in what might otherwise appear to be inhibition, processes such as selective rehearsal and the implementation of schemas or the use of organizational strategies. All of these are non-inhibitory processes that bring the relevant experience of the past to bear on interpreting and acting on the present.

A critic might say that this entire chapter has simply been railing about an ill-defined word, and attempting to define it better. We would agree that this is part of our mission, and would further argue that we do need to be careful about our terminology.[8] Yet the reification of inhibition from the neural to the mental is not what we see as meant by linking neural to mental, because the meaning of the word differs in the two domains. Our intention certainly has been more than merely to clarify a word. Our goal has been to challenge the concept of cognitive inhibition, proposing instead that processing records in memory are not truly suppressed. In fact, we maintain that the opposite is the case: Recent processing records are routinely retrieved to assist with current processing, but they have the potential to conflict with that processing, producing a cost instead of a benefit. One implication of these ideas (cf. Huettel & Lockhead, 1999) is that cognitive psychologists should be paying more attention to sequence effects across trials in their supposedly “discrete trials” experiments.

We cannot assert that cognitive inhibition is impossible, now and forever. Rather, we hope to have presented a challenge to the invocation of inhibitory explanations whenever performance is poorer than in some baseline condition. We have tried to show that other non-inhibitory processes can produce the same behavioral cost. That cost is something to be explained, not to be renamed. As Klein and Taylor (1994, p. 146) put it: "there is as yet no established method for distinguishing between those forms of interference which are likely to depend on inhibitory mechanisms and those which reflect processes such as response competition or fatigue." Cognitive psychologists must define what they mean by inhibition and establish criteria for its occurrence—and its non-occurrence. At the same time, we must consider how to differentiate possible inhibitory processes from alternative non-inhibitory processes. We hope that this chapter has provided some measure of motivation for taking up this challenge.

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Footnotes

[1]The concept of inhibition has also been applied in another domain of behavior: making a physical response. The question here is whether, and if so how, we can restrain an otherwise prepared response. The most concerted attack on this question has used the stop signal paradigm of Logan and his colleagues (De Jong, Coles, & Logan, 1995; Logan & Cowan, 1984; Logan & Irwin, 2000; Logan, Schachar, & Tannock, 1997). On some proportion of trials, the participant is signalled not to make an otherwise appropriate physical response. The evidence is clear that people can successfully cancel a planned movement, given sufficient notice. We also do not wish to contest this motor sense of inhibition. It is interesting that writers at the turn of the century also often saw motor inhibition as qualitatively different from cognitive inhibition. Thus, in listing five potential varieties of inhibition, Breese (1899, pp. 12-13) saw only the last one, which he called "inhibition as a psychophysical phenomenon," as plausible. The first four were all concerned with inhibition of ideas and associations; the final one related to motor inhibition. We would argue that this motor sense of inhibition is different from the sense applied to attention, memory, and other cognitive activities. We accept that physical responses can be planned and then cancelled.

[2]Intriguingly, Sherrington (1951), who is often cited as the "father" of neural inhibition, credits Descartes with introducing the idea of inhibition to physiology, although Descartes' view was of two opposing excitations, not an excitation and an inhibition.

[3]Our citation of these articles is based on the discussions by Diamond et al. (1963) and by Smith (1992). The original sources are, respectively, in German and Latin.

[4]MacLeod and Daniels (2000) recently showed that on both explicit and implicit tests of memory, it is only when the encoding is non-optimal that selective rehearsal can operate to produce a directed forgetting effect.

[5]There is a remaining puzzle: How can the selective rehearsal account explain the apparent absence of a directed forgetting effect on a recognition test under the list method? We suggest two possible answers. First, the size of the effect ordinarily seems to diminish from recall to recognition under the item method. Given the larger effect in recall under the item method than under the list method, a corresponding reduction from recall to recognition may drive the effect size in list method recognition to the floor. Second, recognition may not show serial position effects as strongly as does recall (see, e.g., Cohen, 1970; Kintsch, 1968), so if the list method effects are serial position effects, they may not be visible in recognition.

[6]Recent work is calling into question whether, indeed, age-related declines are related to increased inhibition or to some other factor correlated with aging. Shilling, Chetwynd, and Rabbitt (2002) argue that other factors such as speed and intelligence may not have been as well ruled out as would be desired in studies of aging that have pointed to poorer inhibitory control.

[7]It has not escaped our attention that any discrimination of an improvement or a decrement in performance is necessarily with respect to some baseline. This, in turn, places a huge weight on choosing a suitable baseline from the outset, and we realize that this is a very complex problem that deserves a considerably more thorough discussion than we can undertake here.

[8]In this regard, we recommend not naming phenomena after theories that are proposed to explain them. If, for example, it turns out that there is no inhibition in inhibition of return, this name becomes anachronistic and rather misleading. A better name might have been something like the “location repetition cost,” to avoid grafting theory to phenomenon.

Acknowledgments

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Figure Captions

Fig. 1. The negative priming paradigm (see Fox, 1995, May et al., 1995, for reviews). Shown are example prime and probe trials and illustrative response times from the critical probe trial. Note that participants would be naming the bold italicized target word on each trial (which would actually be presented in red, with the ignored distractor word presented in white).

Fig. 2. Negative priming appears when there is a stimulus mismatch between the prime and probe trials, in the "constant red-red" condition, but disappears when this mismatch is removed, in the "switch red-white" condition. The data are from MacLeod, Chiappe, and Fox (in press), collapsed over the identity conditions in the main and replication experiments.

Fig. 3. The standard inhibition of return procedure, after Posner and Cohen (1984). The cue location is independent, and therefore non-predictive, of the target location. The variable time between the cue and target is referred to as the cue-target onset asynchrony.

Fig. 4. Typical findings in the inhibition of return procedure, from Posner and Cohen (1984). At short cue-target onset asynchronies (0, 50, or 100 ms), the cue facilitates detection of the target; at longer cue-target onset asynchronies (300 or 500 ms), the cue inhibits detection of the target.

Fig. 5. The two standard procedures in directed forgetting (see MacLeod, 1998, for a review). In the item method, each item is followed by an instruction pertaining to that item only; in the list method, there is an instruction to forget the first sublist

at the middle of the list and an instruction to remember the second sublist at the end of the list.

Fig. 6. The standard pattern of directed forgetting effects for the two methods. In the item method, shown in the left panel, the Remember-Forget difference appears in both recall and recognition; in the list method, shown in the right panel, the Remember-Forget difference is restricted to recall. The data are from MacLeod (1999).

Fig. 7. Recall for two groups of participants who were warned (*delay – warning*) or were not warned (*delay – no warning*) about being tested on F items following a delay, and for a group with neither delay nor warning (*no delay*). The left panel shows the low-memory participants; the right panel shows the high-memory participants. The data are from Sheard, Dodd, Wilson, and MacLeod (2002).

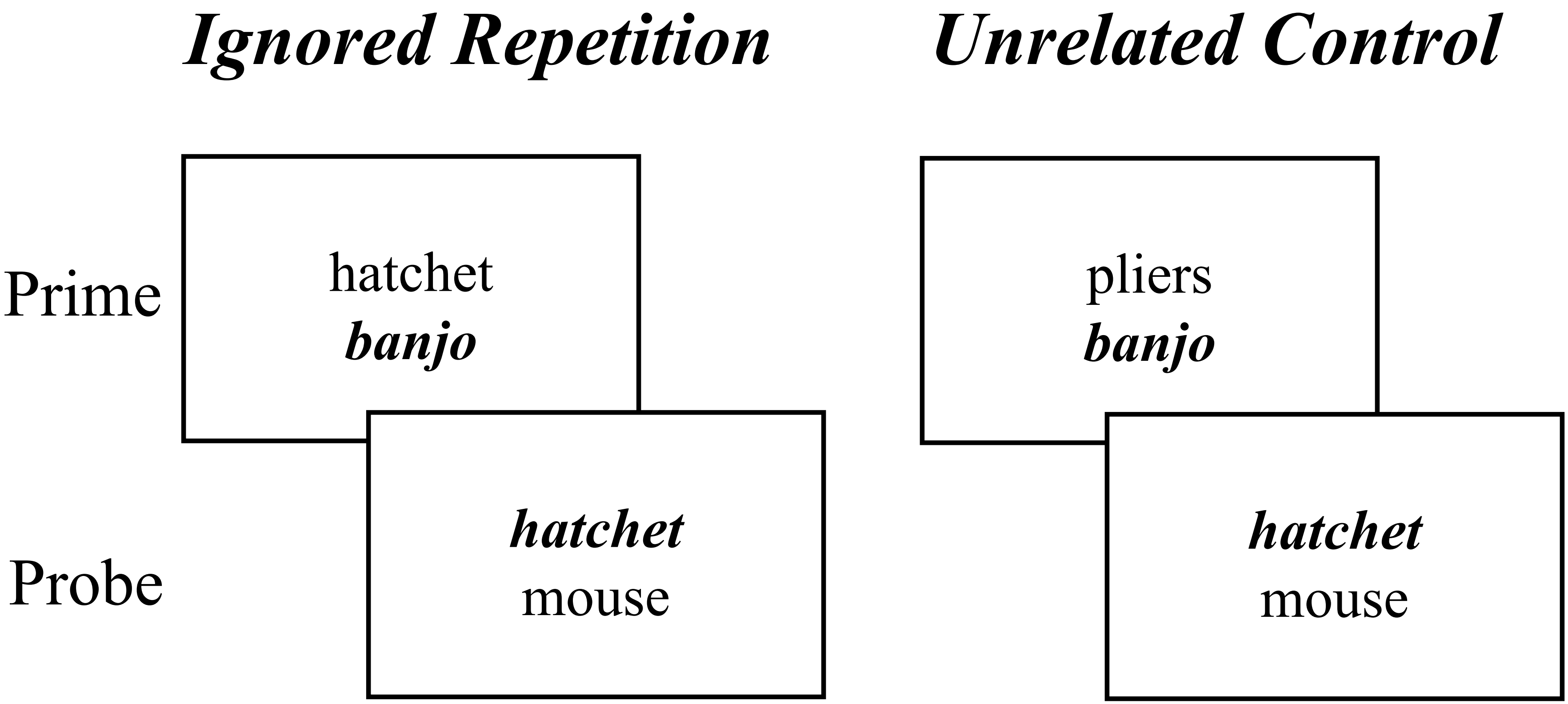
Fig. 8. Free recall serial position functions for the F (first) sublist and the R (second) sublist from a standard F-R list in a within-subject directed forgetting study. The F sublist shows diminished primacy and recency with respect to the R sublist. The instruction to forget the first half of the list clearly does not influence all items in the F sublist equally, which implicates rehearsal as critical to the difference between the F and R items. The data are from Sheard and MacLeod (2002).

Fig. 9. Free recall serial position functions for the F sublist vs the R sublist in a between-subject directed forgetting study. Three groups—an F-R group (For), an R-R group (Rem), and an R-R group told not to rehearse after the first sublist (Rem-NR)—are contrasted, with comparisons made on only their first sublists. The first

R sublist of the R-R group shows more primacy than the F sublist of the F-R group. However, the first R sublist of the R-R group told not to rehearse behaves much like the F sublist of the F-R group. This implicates rehearsal as critical to the difference between the F and R items. The data are from Sheard and MacLeod (2002).

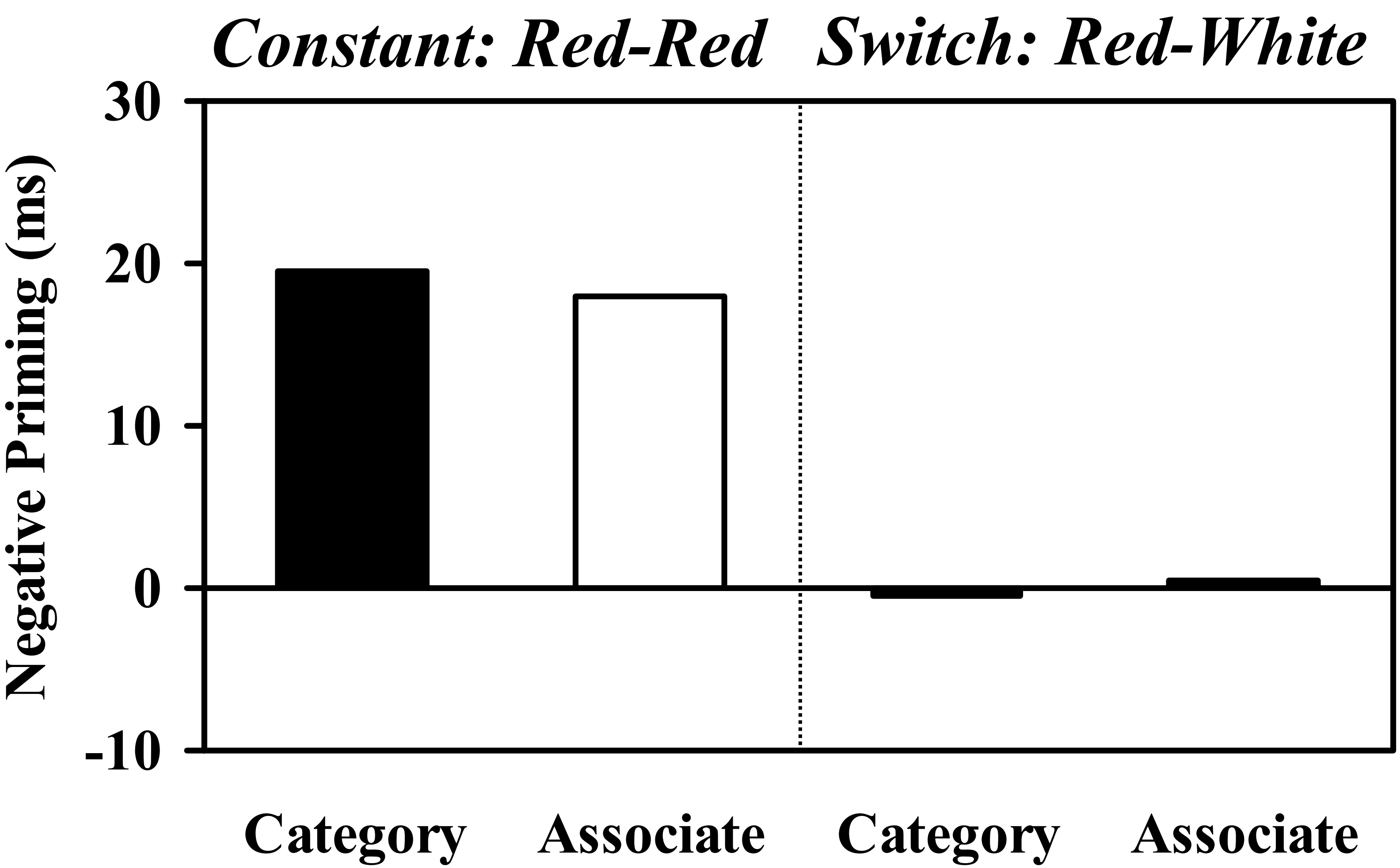
Fig. 10. The procedure used by Anderson, Bjork, and Bjork (1994, Experiment 1) to produce the retrieval-induced forgetting data pattern. *Fruit: Orange* is an example of a strong exemplar; *Tree: Hickory* is an example of a weak exemplar. In the first phase, a list of 48 category-exemplar pairs was studied. This was made up of 8 categories, 4 containing strong and 4 containing weak exemplars, with 6 exemplars per category. In the second phase, half of the exemplars (3) from half of the categories (2 weak and 2 strong) were repeatedly retrieved with a stem cue, such as *Fruit: Or*____. In the final phase, category cues were presented for recall of all items from all categories.

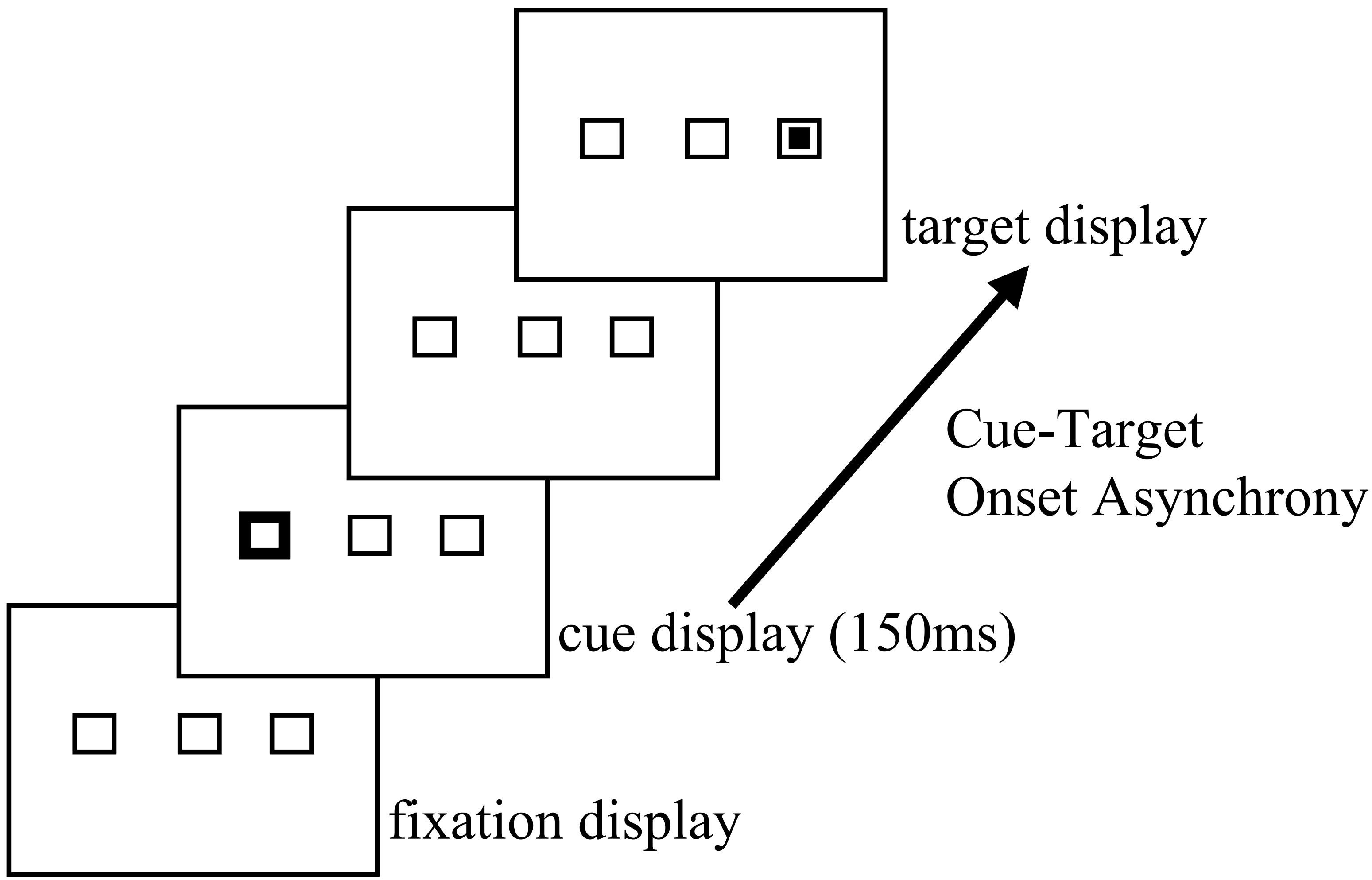
Fig. 11. The mean proportions of items correctly recalled on a category-cued recall test as a function of (1) whether the items were strong or weak exemplars within their categories and (2) whether they were from a practiced category and received retrieval practice (P-P), were from a practiced category and did not receive retrieval practice (P-U), or were from an unpracticed category (U-U). The data are from Experiment 1 of Anderson, Bjork, and Bjork (1994).

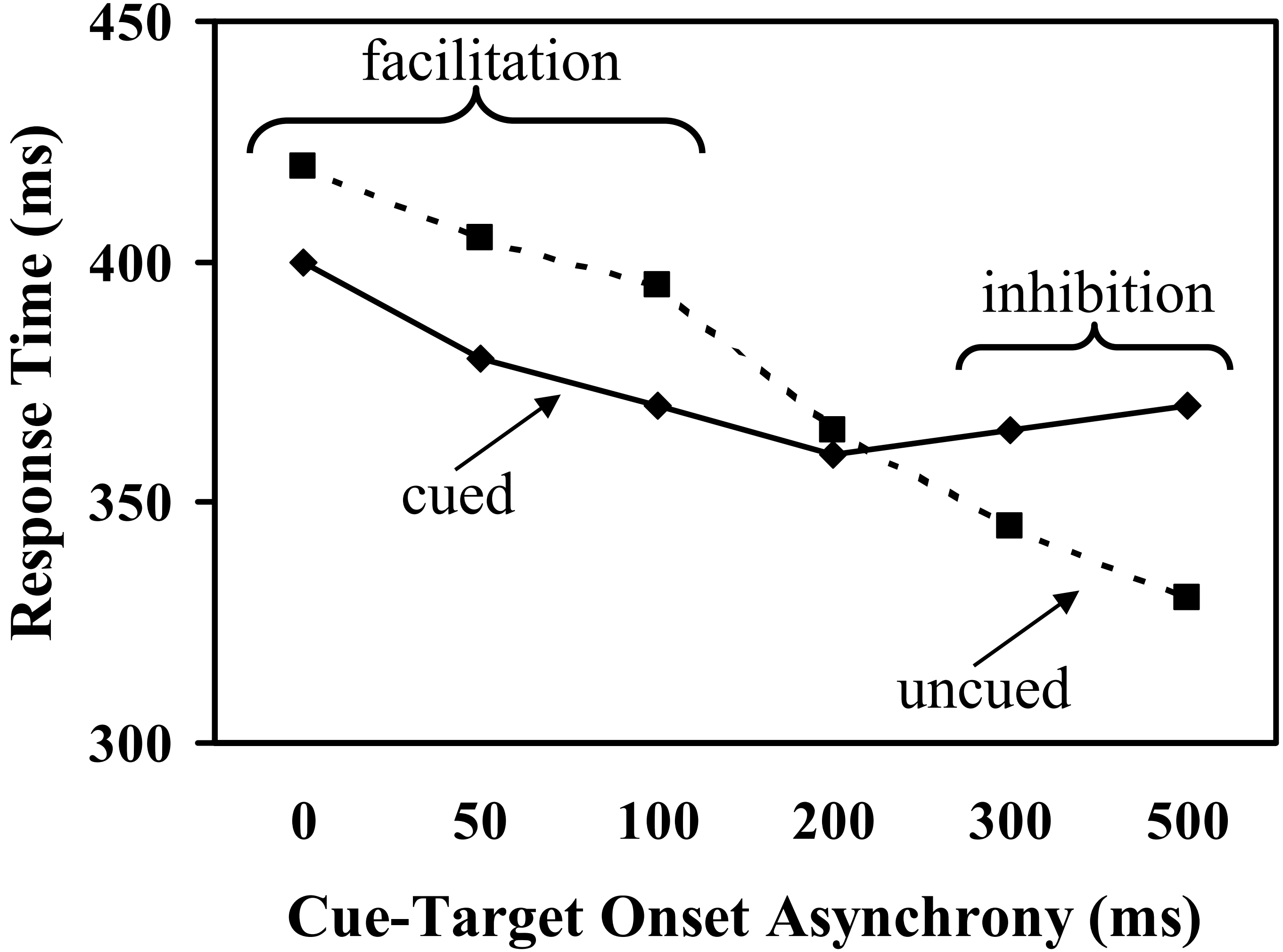


Probe Naming RT = 630 ms (Ignored Repetition)
610 ms (Unrelated Control)

Negative Priming = 20 ms (Ignored – Unrelated)

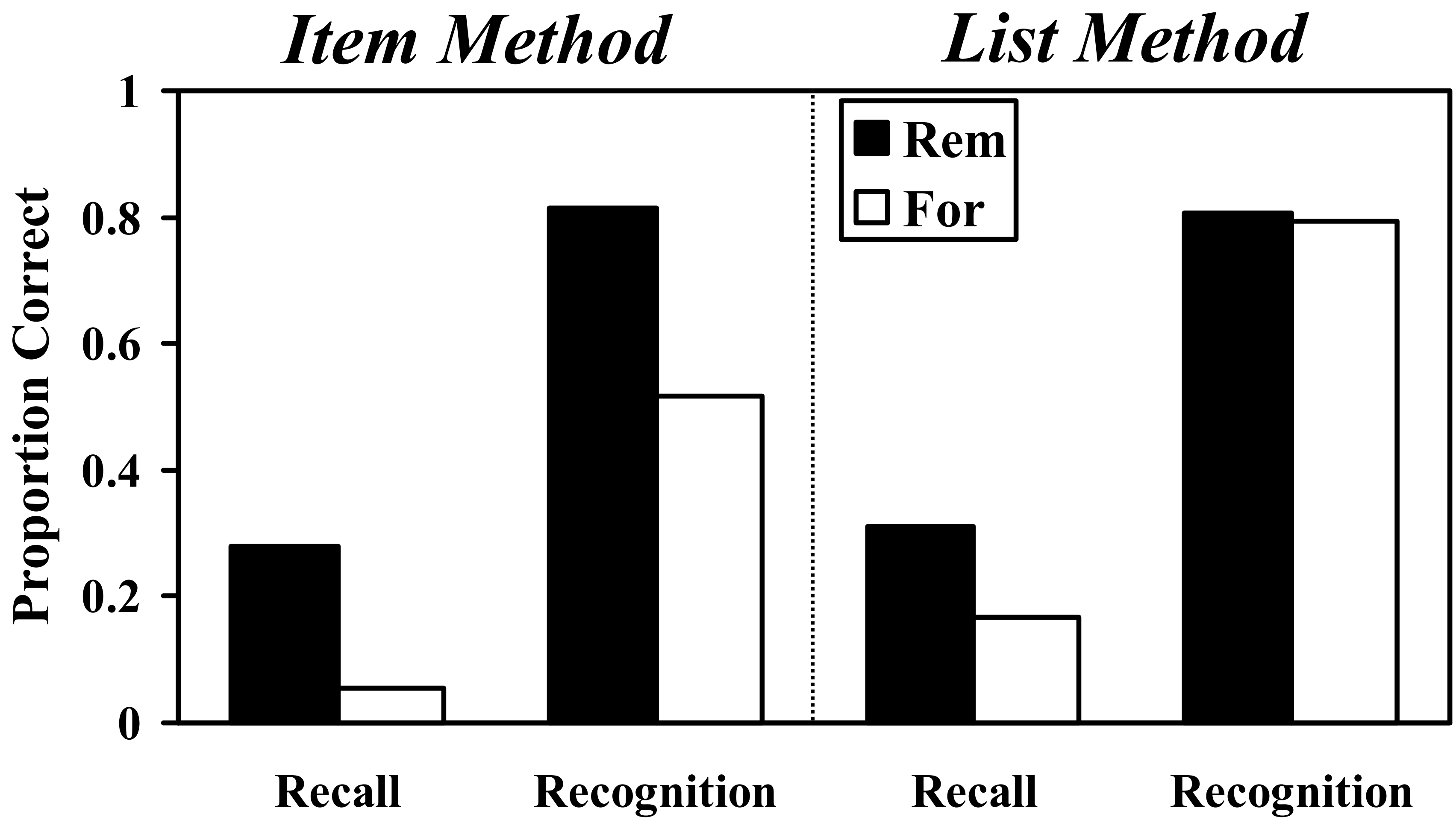

Constant: Red-Red
Switch: Red-White
30
20
10
0
-10
Negative Priming (ms)
Category
Associate
Category
Associate

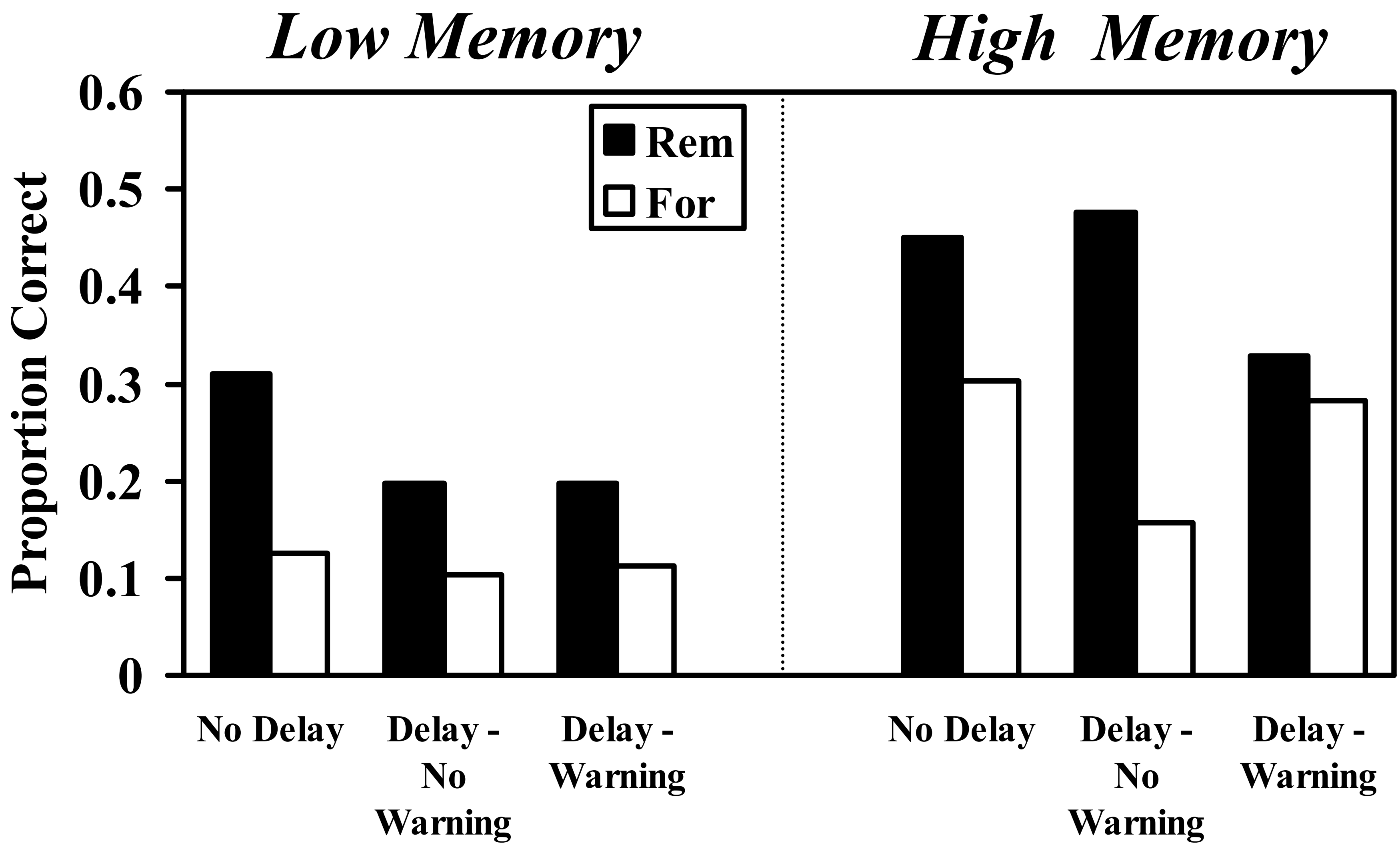

target display
Cue-Target
Onset Asynchrony
cue display (150ms)
fixation display

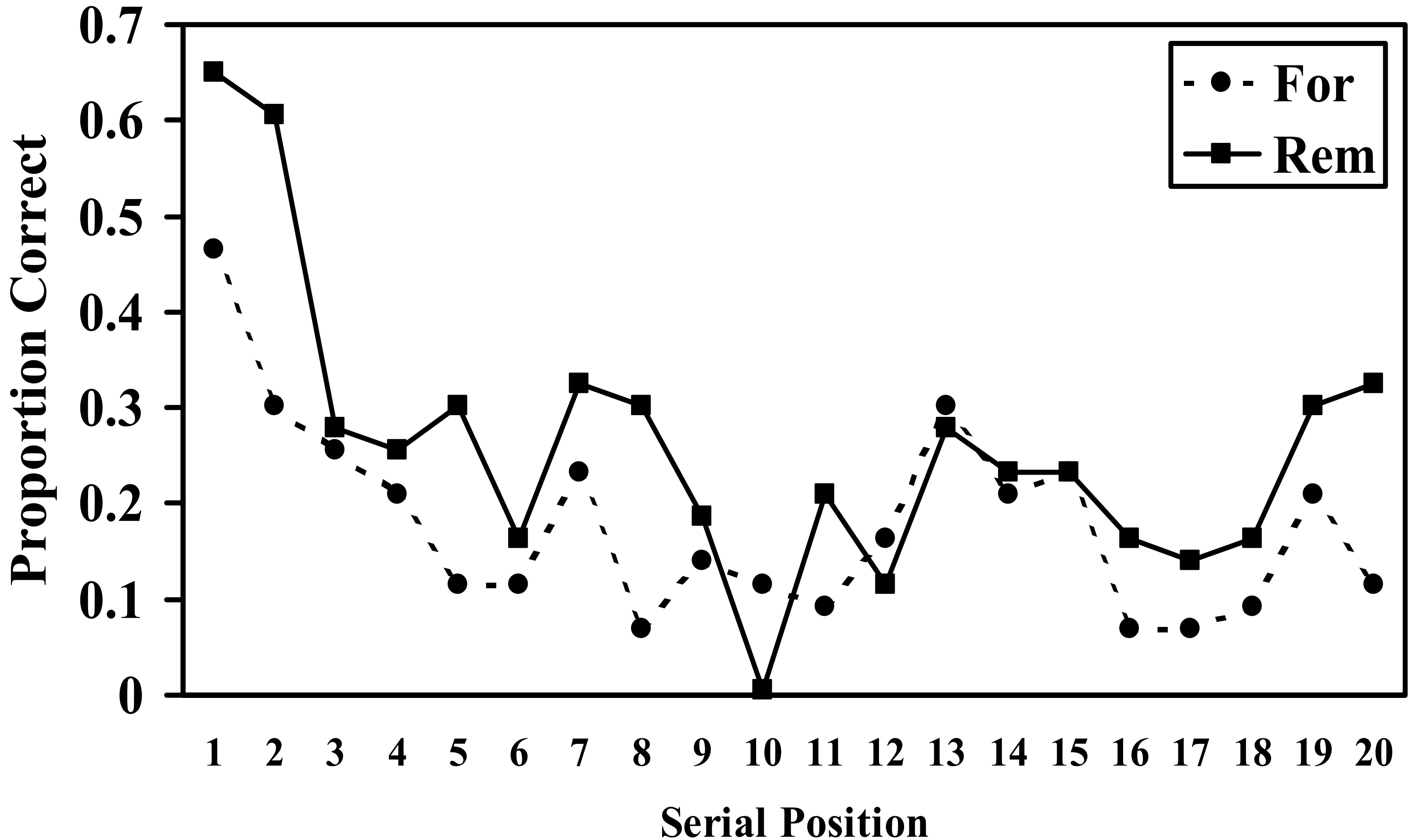


facilitation
inhibition
cued
uncued
450
400
350
300
0
50
100
200
300
500
Response Time (ms)
Cue-Target Onset Asynchrony (ms)

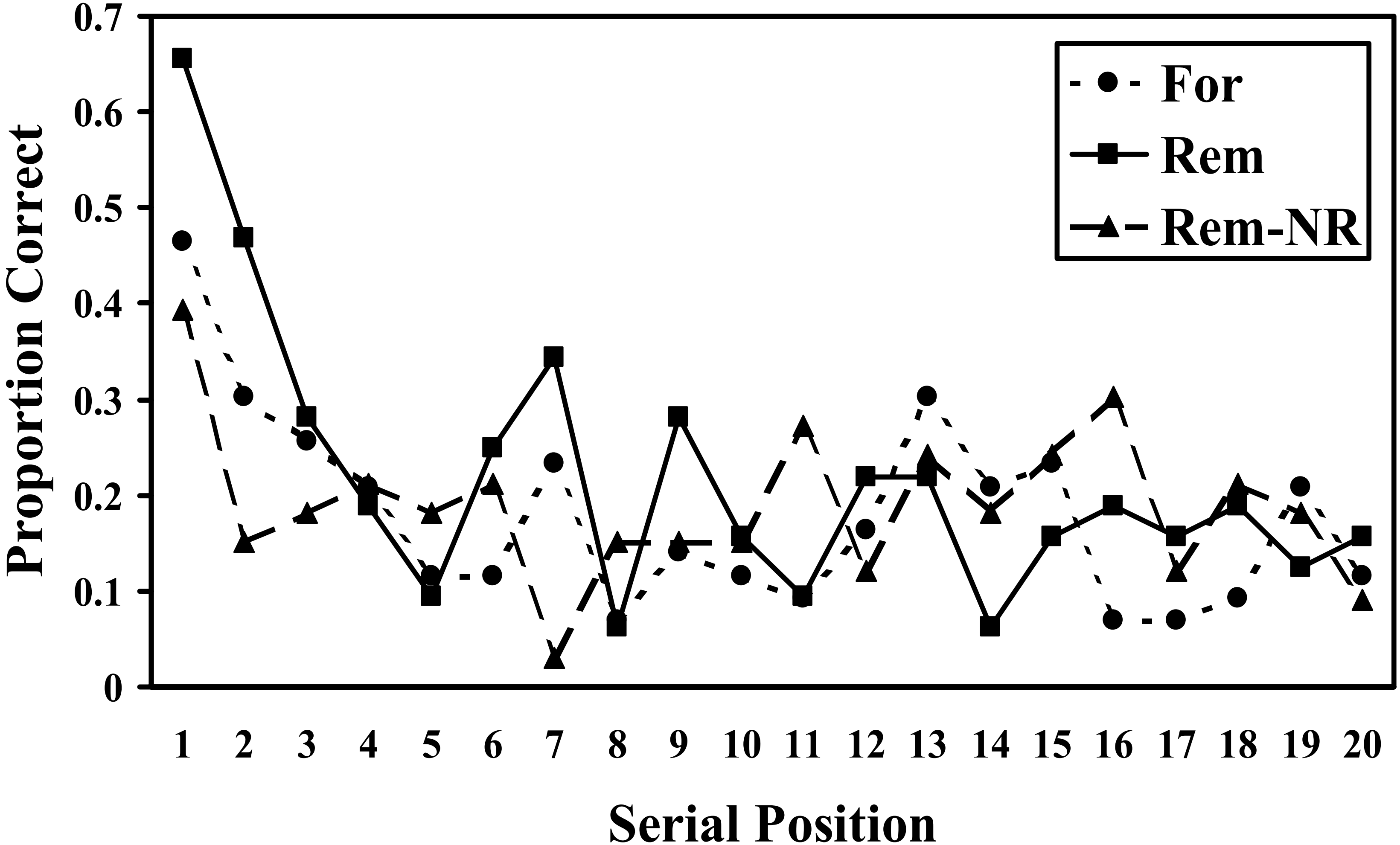
Item Method	***List Method***
…	…
table	table
FFF	cheese
friend	friend
RRR	***FFF***
apple	apple
RRR	horse
horse	truck
FFF	…
…	***RRR***

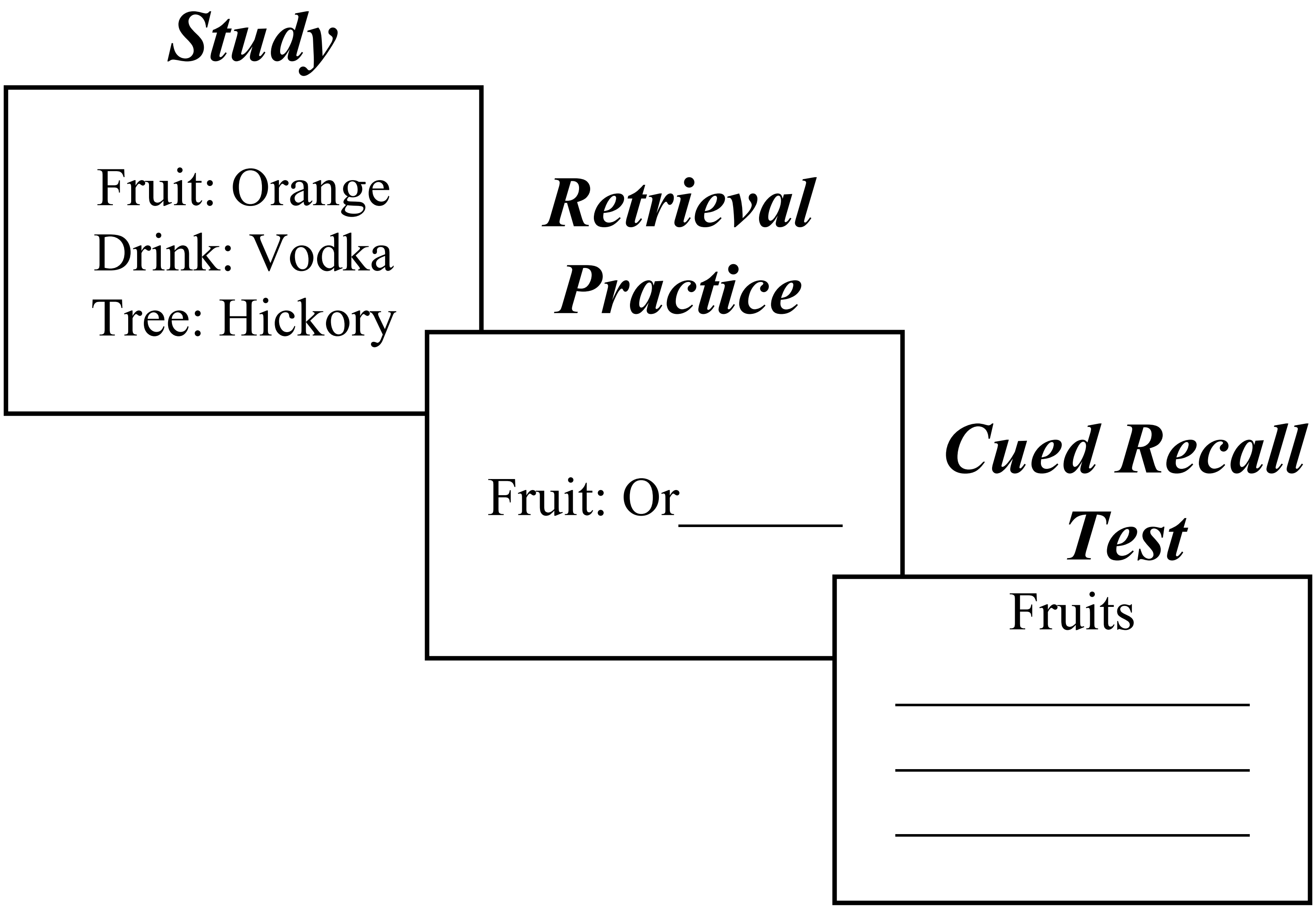

Item Method
List Method
Proportion Correct
1
0.8
0.6
0.4
0.2
0
Rem
For
Recall
Recognition
Recall
Recognition

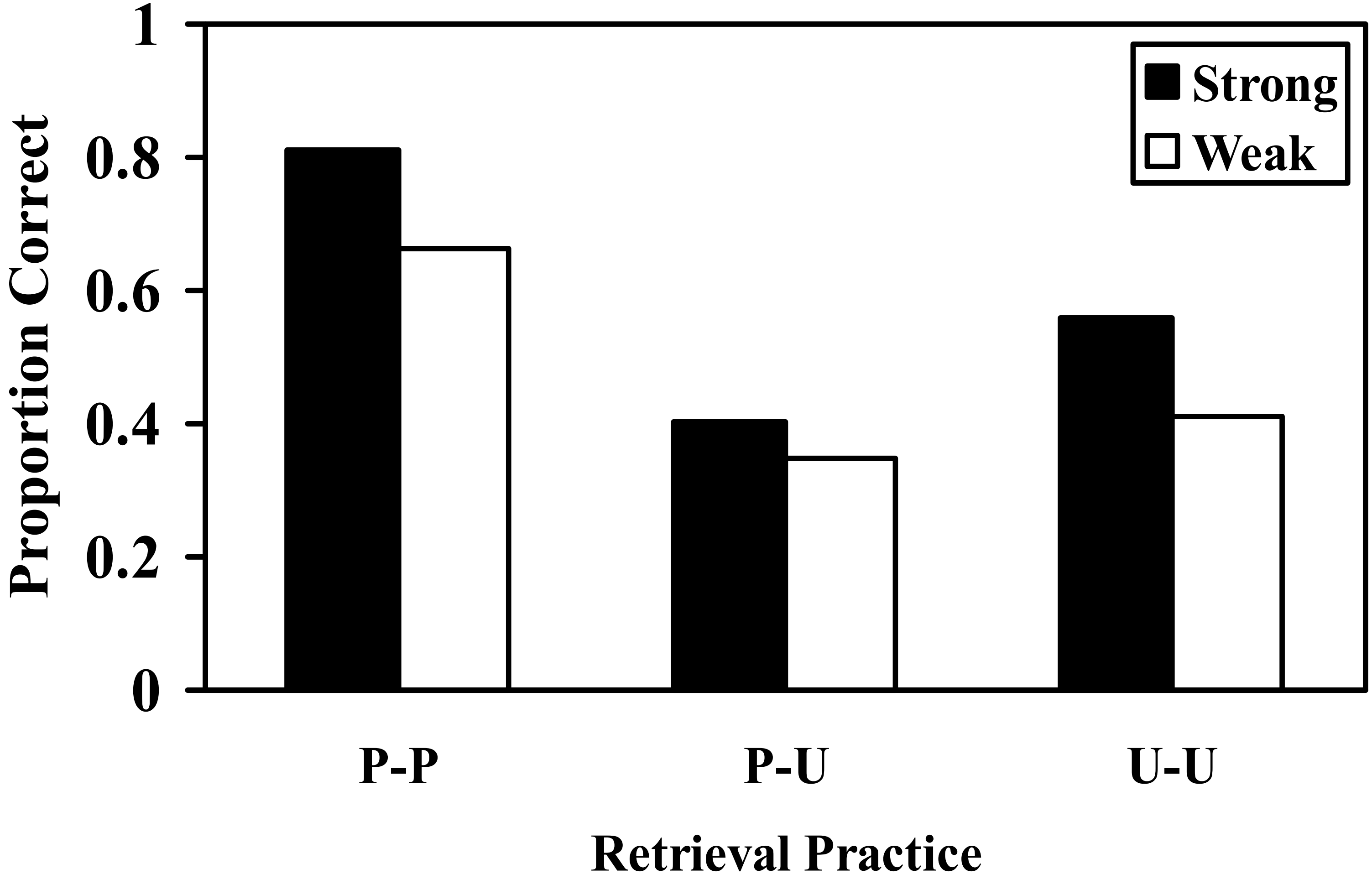

Low Memory
High Memory
Proportion Correct
0.6
0.5
0.4
0.3
0.2
0.1
0
Rem
For
No Delay
Delay - No Warning
Delay - Warning
No Delay
Delay - No Warning
Delay - Warning



For
Rem
Proportion Correct
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Serial Position


Proportion Correct
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Serial Position
For
Rem
Rem-NR


Study
Fruit: Orange
Drink: Vodka
Tree: Hickory
Retrieval Practice
Fruit: Or_______
Cued Recall Test
Fruits


1
0.8
0.6
0.4
0.2
0
Proportion Correct
Strong
Weak
P-P
P-U
U-U
Retrieval Practice