Inhibition in Long-Term Memory

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Many of the concepts discussed in this volume are concerned with mechanisms that enable or enhance memory. To see memory only through this lens of facilitatory mechanisms however, is to miss a class of processes vital to its proper functioning: inhibition. Inhibition refers to a mechanism that acts upon a memory trace to induce a potentially reversible change in its state, making the trace less accessible. At first blush, the idea of a process that impairs memory might seem odd, because forgetting is considered undesirable by most people. More often than people realize, however, having good memory for a prior experience is not what we want. We are frequently confronted with intrusive remindings that undermine performance on some task or that otherwise distract us. Sometimes, these remindings are unpleasant—memories of trauma or loss, or of events that make us sad, anxious, or embarrassed. Other times, our motives for controlling unwanted memories may be utilitarian, as when we simply need to ensure that only the most current knowledge is accessed (e.g., today's parking spot, and not yesterday's). When unwanted memories intrude into mind, some means of reducing their accessibility becomes desirable (Anderson, 2003; Bjork, 1989).

In this chapter, I discuss the idea that inhibition functions to regulate the accessibility of unwanted traces in memory. In the first section, I provide a brief overview of key theoretical attributes of inhibition, and my general perspective on the functions that this process serves in memory. I then illustrate these functions and attributes with examples from research on the role of inhibitory control in forgetting.

The Concept of Inhibition

To understand the role of inhibition in memory, it is useful first to elaborate on four attributes of the concept of inhibition alluded to in the previous definition. First, the

term inhibition implies the operation of an external mechanism that acts upon a memory trace to affect it. The term does not refer to just any process that changes a memory; it specifically excludes, for example, changes in the structural integrity of a memory that were not induced by an external process (e.g., memory decay over time). Second, inhibitory mechanisms modify the state of a trace. This claim implies more broadly that (a) independent of its associative connections to other traces, a memory has an intrinsic state of excitation that also influences its accessibility, and that (b) that state can be altered by inhibition. Third, the reduction in activity state renders the trace less accessible. So, for example, a trace to which inhibition has been applied would be less accessible to retrieval, leading to impaired recall. Finally, the change in a memory's state is often thought to be reversible, so that a memory can regain some of its accessibility lost to inhibition. This reversibility feature contrasts with permanent changes to a trace, such as unlearning, that might affect the structural integrity of the memory.

Most inhibition theorists also believe that inhibition is engaged to achieve at least one of two essential computational functions: to resolve competition between representational or processing structures for control of behavior, or to stop an action or process. Thus, when multiple responses are activated by a cue, or a process simply needs to be disengaged, some mechanism must be recruited to limit the influence of undesired actions. The idea that inhibition responds to competition or the need to stop is clearly reflected in work on memory control, to which I turn next.

The Role of Inhibition in Memory Control

Over the last ten years, my colleagues and I have examined the role of inhibition in controlling the influence of unwanted memories. A central claim of our work is that

people control unwanted memories by recruiting inhibitory mechanisms similar to those used to control overt action (*Anderson, 2003*). By this view, memory control is an instance of a broad class of situations widely acknowledged to require executive control: response override. In response override, one must stop a strong habitual response to a stimulus due to situational demands. For example, each of us has reflexively tried to catch a falling object. If the object is a cactus, however, this reflex needs to be stopped to prevent a painful outcome. The ability to override habitual responses such as this is thought to be supported by mechanisms that inhibit the response. If inhibition is central to stopping action, might it also be engaged to control internal "actions," like retrieval?

My research has examined inhibition in two memory situations likely to require response override: the need for selection during retrieval and the need to stop retrieval itself. In both cases, overriding unwanted memories appears to impair memory in a manner consistent with inhibition. I discuss these two situations in turn.

Inhibition in Selective Retrieval. The role of inhibition in selective retrieval can be illustrated through the phenomenon of retrieval-induced forgetting. A central problem during retrieval is how we access a particular target trace when the cues guiding retrieval are related to many memories. A century of research shows that storing similar competing traces in memory impedes retrieval and increases the chances of a retrieval error. While calling a friend, you may dial their old telephone number by mistake, or while leaving work, you may accidentally walk to yesterday's parking spot. Such memory intrusions are at best distracting, and at worst, dangerous. According to the response override view, memory intrusions trigger control mechanisms that inhibit the unwanted trace. If the effects of inhibition persist, they may be detected by examining

later recall of the distracting trace. Thus, this view makes a counter-intuitive prediction: the very act of remembering should cause forgetting. My colleagues and I have referred to this predicted effect as *retrieval-induced forgetting (Anderson, Bjork, & Bjork, 1994).*

We have tested this prediction with a paradigm known as the retrieval-practice procedure (*Anderson, Bjork, & Bjork, 1994*). In an early version, subjects first studied categories (e.g., Fruits, Drinks) and then performed "retrieval practice" on some of the exemplars of some of those categories (e.g, half the fruits). The purpose of retrieval practice was to examine the impact of retrieval on the later accessibility of other related exemplars that were not practiced (e.g., the other half of the Fruits), compared to recall of unpracticed and unrelated baseline categories (e.g., Drinks). On a final test on all of the members of all the studied categories, Anderson et al. (1994) found that the practiced exemplars were recalled significantly better than baseline. In contrast, the unpracticed exemplars from practiced categories were recalled more poorly than baseline items. This retrieval-induced forgetting effect has been found in a broad range of circumstances, including the retrieval of facts, word meanings, autobiographical memories, and eyewitness memory (see Levy & Anderson, 2002; Anderson, 2003 for reviews). Thus, these findings suggest that selectively retrieving target traces engages inhibitory control mechanisms that suppress competing memories.

The impaired recall of unpracticed items implies some active process that increases the rate of forgetting for competing items, beyond what would be expected by the passage of time. However, the enhanced forgetting does not by itself imply that inhibition was at work because there are many ways that recall can be impaired without inhibition (Anderson & Bjork, 1994). The claim that inhibition underlies retrieval-

induced forgetting amounts to the specific claim that the memory traces of the affected items have been reduced in their activation level by an activation-reducing process that functions to overcome interference, and that memory impairment derives from this change in state. Supporting this claim requires more specific evidence.

Over the last decade, we have evaluated the inhibition view by establishing core theoretical properties of retrieval-induced forgetting that uniquely support inhibition. For example, retrieval-induced forgetting has been shown to exhibit (a) *interference dependence*--- retrieval only inhibits related traces if they interfere with retrieval, consistent with the idea that inhibition functions to resolve competition (*Anderson et al. 1994; Shivde & Anderson, 2001*); (b) *retrieval-specificity*—other forms of practice that do not require retrieval (e.g., extra study) do not suppress related traces, showing that impairment only occurs when intrusive memories need to be overridden (*Anderson, Bjork, & Bjork, 2000; Ciranni & Shimamura, 1999; Bauml, 2002*); and (c) *cue-independence*--- impairment generalizes to novel final test cues unrelated to those used for retrieval practice (e.g., *Anderson & Spellman, 1995, Anderson & Bell, 2001; Anderson, Green, & McCulloch, 2000; Johnson & Anderson, 2004*). Retrieval-induced forgetting also occurs on tests of item accessibility, including item recognition (Hicks & Starns, 2004), and even lexical decision (Veling & van Knippenberg, 2004), confirming that impairment reflects a change in the state of the affected item, and not some change extrinsic to the item (see Anderson & Bjork, 1994; Anderson & Spellman, 1995; and Anderson, 2003, for arguments). And finally, retrieval-induced forgetting has been found to recover after 24 hours (MacLeod & Macrae, 2001), suggesting that in at least some cases, impairment reflects a reversible change in state. However, the evidence base on

reversibility is still maturing (see Anderson, 2003, Anderson & Spellman, 1995, for an alternative perspective on why inhibition may not necessarily recover with time).

Together, these findings show that retrieval engages inhibition to overcome interference from competing memories, rendering them less accessible generally (see Anderson, 2003 for a review).

Inhibition in Memory Stopping. A second situation likely to engage response override is the need to stop retrieval entirely. So, for instance, upon confronting a reminder to an unpleasant memory, we may engage inhibition to stop retrieval, preventing the reminder from eliciting the unwanted memory. Can the mechanisms that stop reflexive responses be engaged to override retrieval? To study this, we developed the think/no-think paradigm (*Anderson and Green, 2001*), which puts people in a situation in which they must confront a reminder to a memory, while willfully excluding that memory from consciousness. To achieve this, subjects first studied cue-target pairs (e.g., *flag–sword*, *ordeal–roach*). Subjects then entered the critical think/no-think phase. For most of the trials, subjects were presented with a cue word and asked to recall the corresponding memory as quickly as possible. For certain cues, however, subjects were admonished to avoid consciousness of the associated memory. These latter trials mimic situations in which we confront a reminder to an unwanted memory and must avoid thinking about it.

How did subjects' efforts to exclude the unwanted memories from consciousness influence their ability to later access those memories? After the think/no-think phase ended, subjects were given all of the cues, but were now asked to recall the response for each of the pairs As might be expected, words that subjects thought about during the

think/no-think phase showed improvement. More striking was the finding that avoided memories not only failed to improve from the repeated reminders, their retention was impaired compared to baseline items that were learned initially, but for which no reminders were presented in the interim. This impairment is highly counter-intuitive given that subjects encountered the reminder cues to forgotten items as many as 16 times during the think/no-think phase. Importantly, the impairment was also observed when subjects were provided with a novel cue for the item (see Figure 1). This finding shows that subjects were not merely suffering associative interference, but rather that the memory itself had been inhibited, impairing its recall generally.

Recent findings confirm that the brain mechanisms underlying memory inhibition may be related to the ability to override reflexive responses generally. Suppressing unwanted memories recruits the dorsolateral prefrontal cortex, a brain region associated with the inhibition of prepotent responses; this suppression leads to reduced activation in the hippocampus, a structure associated with declarative memory (Anderson et al., 2004). Importantly, the engagement of frontal cortex and the modulation of hippocampal activation predict how impaired memory will be for suppressed items. Whether the memory impairment produced by suppression reflects direct or indirect consequences of neuronal inhibition remains an open question, although the impairment appears to be related to modulation of brain activity at the systemic level.

The capacity to voluntarily inhibit unwanted memories observed in this work may help people regulate consciousness of unpleasant or intrusive memories. This may provide a mechanistic basis for the voluntary form of repression (suppression) proposed by Freud (*Anderson & Green, 2001; Anderson et al., 2004*).

Concluding Remarks

Taken together, the patterns observed in retrieval-induced forgetting and active memory suppression suggest that many of our experiences of forgetting are produced by an inhibition process that regulates the accessibility of memory traces. Many other phenomena in memory may be produced in whole or in part by inhibition, including retroactive interference (Bauml, 1996), part-set cuing inhibition (Bauml & Aslan, 2004), and output interference (Bauml, 1998). If correct, this view suggests a new perspective on forgetting that contrasts with the passive view that has prevailed in psychology for much of its history—a new perspective that emphasizes the role of control processes in regulating the accessibility of our knowledge and of experience to accommodate the need for focused, goal-directed cognitive activity.

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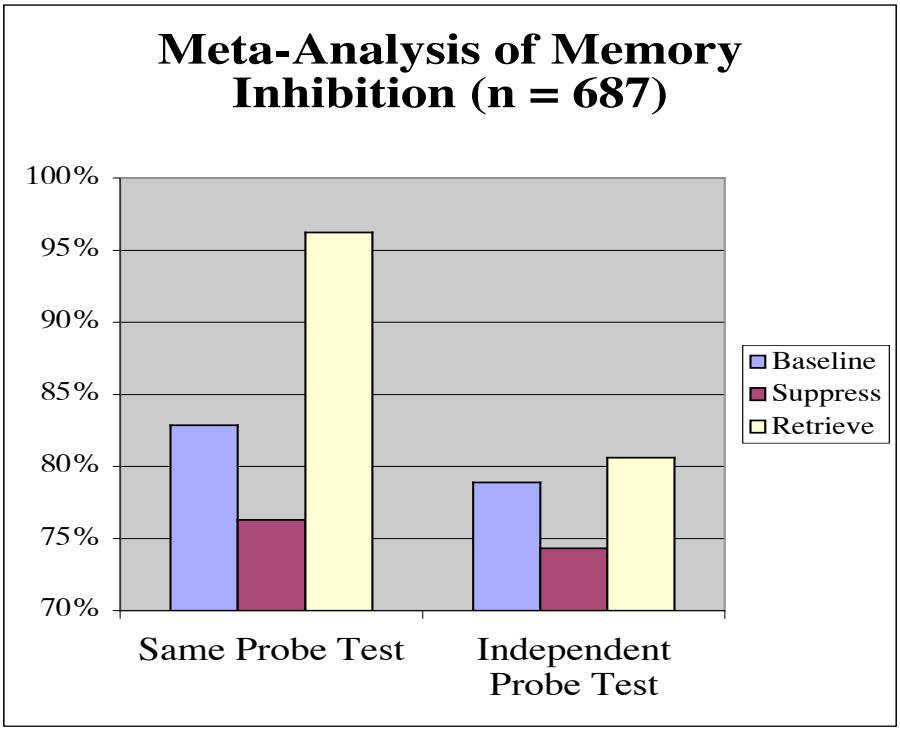
Figure Captions.

Figure 1. A meta-analysis of our studies with the think/no-think paradigm. As can be seen, suppressing awareness of the response member of a pair when presented with the stimulus (Suppress condition) impairs recall of that item, compared to baseline performance, whereas thinking of the response member (Retrieve condition) facilitates its recall. This finding occurs both when the item is tested with the original stimulus (Same probe test), as well as a novel cue (Independent probe test), indicating inhibition of the response.


Meta-Analysis of Memory Inhibition (n = 687)
100%
95%
90%
85%
80%
75%
70%
Same Probe Test
Independent Probe Test
Baseline
Suppress
Retrieve