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Inhibition: Manifestations 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 the 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 and graded 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 (Bjork 1989; Anderson 2003).

In this chapter, I discuss the idea that inhibition functions to regulate the accessibility of unwanted traces in memory. The first section reviews key theoretical attributes of inhibition, and the functions that it serves. I then illustrate these attributes and functions with examples from research on the role of inhibitory control in forgetting.

The concept of inhibition

The previous definition points to four important attributes of inhibition. First, the term inhibition implies a mechanism external to a memory trace that acts upon it. The term does not refer to just any process that changes a memory; it excludes, for example, changes in the structural integrity of a memory that were not induced by an external process (e.g. memory decay). Secondly, inhibition modifies the state of a trace. This claim implies (1) that independent

of its associative connections to other traces, a memory has a state of excitation that influences its accessibility, and (2) that that state can be altered by inhibition in a graded fashion. Thirdly, the reduction in activity renders the trace less accessible, impairing recall. Finally, the change in a memory's activation state is often thought to be reversible, so that a memory can regain some of its accessibility. This reversibility contrasts with permanent changes (e.g. unlearning) that might affect the structural integrity of the memory.

Most inhibition theorists also believe that inhibition achieves at least one of two computational functions: resolving competition between representations or processing structures, or stopping a process. Thus, when multiple responses are activated by a cue, or a process needs to be disengaged, inhibition limits the influence of undesired representations. These ideas are clearly reflected in work on memory control, to which I turn next.

The role of inhibition in memory control

The foregoing properties and functions of inhibition are well illustrated through work on how people control unwanted memories. In my work, for example, I have argued 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 response override, in which 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 is thought to be supported by inhibition. If inhibition is central to stopping action, might it also be engaged to control internal 'actions', such as retrieval?

We have 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 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 (for a review of this literature, see Anderson and Neely 1996). 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 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 inhibition persists, it 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. This predicted effect has been referred to as *retrieval-induced forgetting* (Anderson *et al.* 1994). Retrieval-induced forgetting has been found in a broad range of circumstances, including the retrieval of facts, semantic memories, word meanings, autobiographical memories and eyewitness memory (for reviews, see Levy and Anderson 2002; Anderson 2003).

The impaired recall of unpracticed items implies an active process that increases 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 and 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 by an activation-reducing process that functions to overcome interference, and that memory impairment derives from this change in state.

Several properties of retrieval-induced forgetting specifically favor inhibition, however, and illustrate the concept outlined at the outset of this chapter. For example, retrieval-induced forgetting exhibits (1) *interference dependence*—retrieval only impairs related traces if they interfere with retrieval, consistent with the idea that inhibition resolves competition (Anderson *et al.* 1994); (2) *retrieval-specificity*—other forms of practice that do not require recall (e.g. extra study) do not impair competitors, showing that inhibition only occurs when intrusive memories need to be overridden (Anderson *et al.* 2000); and (3) *cue independence*—impairment generalizes to novel final test cues unrelated to those used for retrieval practice (e.g. Anderson and Spellman 1995). Retrieval-induced forgetting also occurs on tests of item accessibility, including item recognition and lexical decision (Veling and van Knippenberg 2004), confirming that impairment reflects a change in the state of the affected item. Finally, retrieval-induced forgetting has been found to recover after 24 h (MacLeod and Macrae 2001), suggesting that in at least some cases, impairment reflects a reversible change in state (however, see Anderson and Spellman 1995; Anderson 2003, for an alternative perspective on why inhibition may not recover with time). Together, these findings show that retrieval engages inhibition to overcome interference from competing memories, rendering them less accessible generally (for a review, see Anderson 2003), illustrating the core concept of inhibition.

Inhibition in memory stopping

A second situation likely to engage response override is the need to stop retrieval. So, for instance, upon confronting a reminder to an unpleasant memory, we may engage inhibition to stop retrieval, preventing the reminder from eliciting the memory. Can the mechanisms that stop reflexive responses be engaged to override retrieval? To study this, we put people in a situation in which they repeatedly confronted a reminder to a recently encoded memory, and asked them to attend to the reminder while willfully excluding the associated memory from consciousness. Afterwards, we asked subjects to recall the memories that they had previously kept out of awareness. Interestingly, the repeated presentations of reminders during the prior no-think phase not only failed to improve people's later retention of the associated memory—as one might ordinarily expect reminders to do—it impaired performance compared with performance on baseline items that were learned initially, but for which no reminders were presented in the interim. Thus, excluding an unwanted memory from awareness leads to a memory deficit for the avoided trace, and the properties of this deficit are consistent with inhibition (Anderson and Green 2001).

Recent findings confirm that the brain mechanisms underlying this type of memory inhibition are related to the ability to override reflexive responses. Suppressing unwanted memories recruits the dorsolateral prefrontal cortex, a brain region associated with inhibiting prepotent responses; this suppression reduces 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 the amount of memory impairment for suppressed items. Whether the forgetting produced by suppression reflects the direct or indirect consequences of neuronal inhibition remains to be established, although the impairment is clearly related to modulation of brain activity at the systemic level. The capacity to inhibit unwanted memories may help people regulate consciousness of unpleasant or intrusive memories.

Concluding remarks

Taken together, the findings on memory inhibition suggest that many of our experiences of forgetting are produced by an inhibition process that regulates the accessibility of memory traces. When a memory interferes with retrieval or is otherwise unwanted, inhibition can be engaged to alter that memory's state of activation, rendering it less accessible when later desired. Although we have discussed inhibition in memory retrieval and retrieval stopping, many other

phenomena may also be produced in whole or in part by inhibition, including the classic concept of retroactive interference (for a review, see Anderson and Neely 1996), part-set cuing inhibition and output interference (see Bauml 1996, 1998; Bauml and Aslan 2004, for evidence concerning the role of inhibition in these phenomena). 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.