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Suppressing Unwanted Memories

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ABSTRACT—*When reminded of something we would prefer not to think about, we often try to exclude the unwanted memory from awareness. Recent research indicates that people control unwanted memories by stopping memory retrieval, using mechanisms similar to those used to stop reflexive motor responses. Controlling unwanted memories is implemented by the lateral prefrontal cortex, which acts to reduce activity in the hippocampus, thereby impairing retention of those memories. Individual differences in the efficacy of these systems may underlie variation in how well people control intrusive memories and adapt in the aftermath of trauma. This research supports the existence of an active forgetting process and establishes a neurocognitive model for inquiry into motivated forgetting.*

KEYWORDS—*executive control; inhibition; forgetting; trauma; memory*

To most people, forgetting is a human frailty to be overcome. More than we realize, however, forgetting is what we want and need to do. Sometimes we confront reminders of experiences that sadden us—as when, after a death or a broken relationship, objects and places evoke memories of the lost person. Other times, reminders trigger memories that make us angry, anxious, ashamed, or afraid. A face may remind us of an argument we regret; an envelope may bring to mind an unpleasant task we are avoiding; or an image of the World Trade Center in a movie may elicit upsetting memories of September 11. When confronting these reminders, a familiar reaction often occurs: a flash of experience and feeling followed rapidly by an attempt to exclude the unpleasant memory from awareness. At such times, memory is too effective and must be overcome. Suppressing retrieval shuts out the intrusive memories, restoring control over the direction of thought and our emotional well-being. For veterans of Iraq and Afghanistan, victims of Hurricane Katrina, witnesses of terrorism, and countless people experiencing personal traumas, the day-to-day reality of the need to control intrusive memories is unfortunately all too clear. Forgetting is their goal, and remembering, the human frailty.

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In this article we review recent research on the cognitive and neurobiological mechanisms supporting the suppression of unwanted memories, focusing on three points. First, stopping retrieval engages inhibitory control processes that make it harder to recall the avoided memory later on. Second, stopping retrieval is accomplished by brain areas similar to those that stop motor responses, which achieve control by reducing activity in brain structures fundamental to memory. Third, people who engage these brain systems effectively are also more successful at suppressing memories, suggesting that difficulties in managing intrusive remindings originate from difficulties in executive control. Collectively, these findings specify a model of motivated forgetting that is of practical importance in understanding and aiding those suffering from intrusive memories.

THE NEED FOR RESPONSE OVERRIDE

Intrusive memories seem to leap to mind in response to reminders, despite attempts to avoid those memories. Indeed, retrieval often occurs involuntarily in response to reminders. A key premise of our research is that controlling unwanted memories builds on mechanisms necessary to stop automatic motor responses. Consider an example of motor stopping. One evening, the first author accidentally knocked a potted plant off his window sill. As his hand darted to catch the falling object, he realized that the plant was a cactus. Mere centimeters from it, he stopped himself from catching the cactus. The plant fell and was ruined, but he was relieved to not be pierced with little needles. This example illustrates the need to override a strong habitual response to a stimulus, which is a basic function of executive control (Fig. 1). Without the capacity to override prepotent responses, we could not adapt behavior to changes in our goals or circumstances. We would be slaves to habit and reflex.

How do we keep from being controlled by habitual actions? One possibility is that we inhibit undesired actions. By this view, when we encounter a stimulus, activation spreads from that cue to possible responses. Activation can be thought of as the amount of "energy" a response has, influencing its accessibility; a response will be emitted once it is sufficiently activated. If one wishes to override the response, one may engage inhibitory control, a subtractive mechanism that reduces the response's activation. Perhaps we control memories in a similar way. Like

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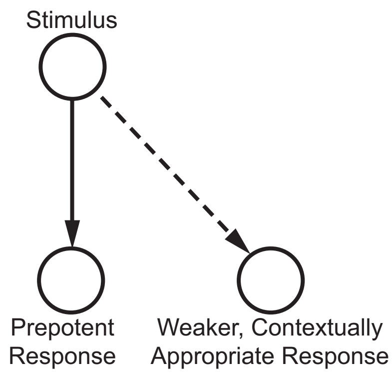

Fig. 1. A typical response-override situation. In such a situation, a stimulus is associated with two responses, one of which is stronger (prepotent) and the other of which is weaker (indicated by the dotted line). Response override occurs whenever one needs either to select the weaker but more contextually appropriate response or to simply stop the prepotent response from occurring. Inhibitory control is thought to achieve response override by suppressing activation of the prepotent response. This basic situation describes many paradigms in research on executive control, including the go/no-go task.

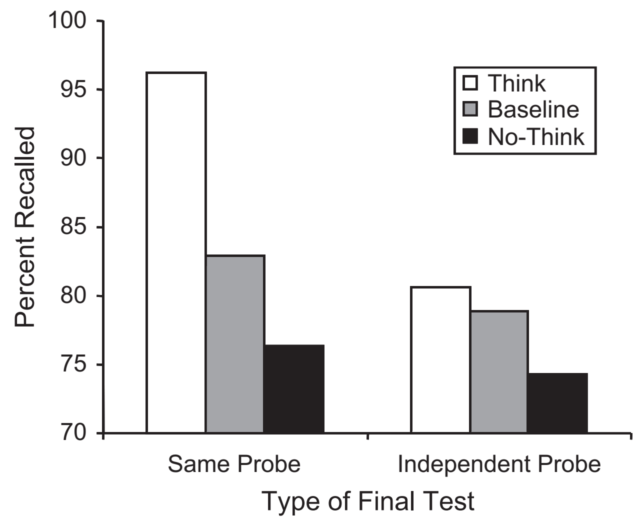

Fig. 2. Final recall performance in the think/no-think (TNT) procedure, aggregating over 687 subjects in many different studies. The graph shows the percentage of items recalled as a function of the whether people thought of the item (think), suppressed the item (no-think), or had no reminders to the item during the think/no-think phase (baseline). The left side of the graph shows recall when tested with the originally trained reminder (i.e, the same probe). Interestingly, forgetting for ''no-think'' items generalizes to when their recall is tested with a novel reminder that was not originally studied (i.e., the independent probe, right side of the graph), such as a category name for the suppressed response, indicating that the negative control effect reflects inhibition of the response.

actions, memories can be triggered by activation spreading from reminders that we encounter. Might inhibition be recruited to stop retrieval, allowing us to avoid catching our "mental cacti"?

STOPPING RETRIEVAL CAUSES FORGETTING

To study how people stop retrieval, Anderson and Green (2001) developed a procedure modeled after the go/no-go task, a paradigm designed to investigate motor stopping. In a typical go/no-go task, participants press a button as quickly as possible whenever they see a letter appear on a screen *except* when the letter is an X, for which they are to withhold their response. Their ability to withhold the response measures inhibitory control over action (e.g., how well a person avoids catching the cactus). To see whether stopping retrieval also engages inhibitory control, Anderson and Green (2001) adapted this procedure to create the "think/no-think" paradigm.

The think/no-think paradigm mimics situations in which we stumble upon a reminder to a memory we prefer not to think about and try to keep it out of mind. Participants study cue–target pairs (e.g., *ordeal–roach*), and are trained to recall the second word (*roach*) whenever they encounter the first word (*ordeal*) as a reminder. Participants are then asked to exert control over retrieval during the think/no-think phase. Most trials require them to recall the response whenever they see the reminder; but for certain reminders, participants are admonished to avoid retrieving the response. It is emphasized that it is insufficient to avoid *saying* the response—they must prevent the memory from entering awareness. Thus, participants have to stop the cognitive act of retrieval. Can people recruit inhibition to prevent the memory from intruding into consciousness?

Since awareness cannot be observed, it is difficult to know whether a person prevents a memory from entering consciousness. Instead, the think/no-think procedure measures the aftereffects of stopping retrieval, based on the idea that inhibition of the unwanted memory might linger, making these memories harder to recall. To assess this behavioral footprint of suppression, a final test is given in which participants again see each reminder and are asked to recall every response they learned earlier. On this test, "think" items are recalled more often than "no-think" items (Fig. 2). This large difference, known as the *total control effect*, demonstrates how the intention to control retrieval modulates later memory. Importantly, a third set of pairs are studied initially but do not appear during the think/no-think phase, providing a baseline for measuring both a *positive control effect* and a *negative control effect* that contribute to the total control effect. The positive control effect reflects enhanced memory for "think" items above baseline recall due to intentional retrieval, confirming that reminders enhance memory when people are inclined to remember. The negative control effect reflects impaired memory for "no-think" items below baseline due to people's efforts to stop retrieval. When people try to avoid being reminded, reminders not only fail to enhance memory, they trigger inhibitory processes that actually impair memory. The negative control effect is striking and counterintuitive, since repeatedly encountering reminders could remind us of the memory, making it more accessible, not less. The negative control effect occurs even when people are paid for each item they remember, making it unlikely that people are simply withholding responses. In contrast, asking people to merely avoid saying the response, instead of avoiding thinking about it, eliminates the negative control effect, isolating the effort to control consciousness as the critical factor causing forgetting.

Can these processes be engaged to control more complex, emotional memories? Recent studies indicate that suppressing retrieval of negative memories causes as great or greater inhibition relative to suppressing either neutral stimuli (Depue, Banich, & Curran, 2006; Depue, Curran, & Banich, 2007) or positive memories (Joorman, Hertel, Brozovich, & Gotlib, 2005). Moreover, the negative control effect generalizes to complex scenes (e.g., a car accident; Depue et al., 2007). Thus, inhibitory control appears effective at suppressing retrieval of more naturalistic memories, strengthening it as a model for how people regulate awareness of unpleasant memories in daily life.

SHUTTING DOWN MEMORY LANE IN THE BRAIN

The preceding sections suggested that people control intrusive memories by engaging systems that suppress overt action. More direct evidence for this relationship is provided by neuroimaging studies that assess whether similar brain systems are involved in stopping retrieval and stopping action. Anderson et al. (2004) used fMRI to contrast brain activity during no-think and think trials and found that suppressing retrieval recruited a network of regions including the lateral prefrontal cortex and anterior cingulate cortex. This network overlaps strongly with the one involved in motor inhibition tasks (such as go/no-go), even though no motor responses were required. The lateral prefrontal cortex, in particular, plays a critical role in stopping reflexive motor responses (e.g., Aron, Fletcher, Bullmore, Sahakian, & Robbins, 2003). In fact, stimulation of this region during a "go" motor response induces monkeys to stop their movement (Sasaki, Gemba, & Tsujimoto, 1989). This overlap suggests that stopping unwanted actions and unwanted memories engages a common neural system. It would be profitable for future studies to directly compare memory and motor inhibition areas in the same people to confirm colocalization of these functions.

But how might brain regions involved in suppressing motor responses control a memory? The answer lies in the brain region targeted by control: the hippocampus. The hippocampus is essential for forming episodic memories (Squire, 1992), and increased hippocampal activation has been linked to consciously recollecting an event. Suppressing an unwanted memory requires that people stop retrieval to prevent conscious recollection. Indeed, hippocampal activity is reduced when participants suppress retrieval compared to when they retrieve a memory, suggesting that people can intentionally regulate hippocampal activation to disengage recollection (Anderson et al., 2004; Fig. 3). Thus, depending on whether or not people wish to be reminded by a stimulus, they are able to control hippocampal activation, influencing retention of that memory.

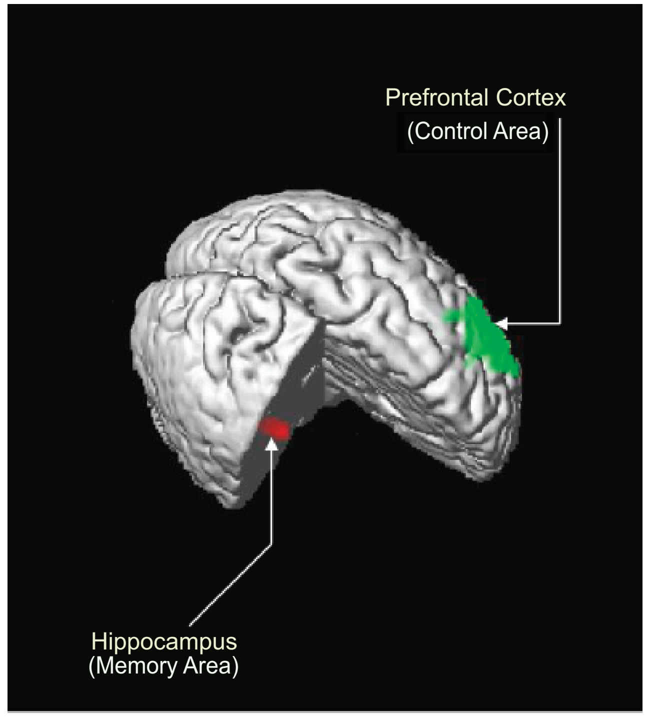

Fig. 3. A schematic representation of the functional magnetic resonance imaging (fMRI) results of Anderson et al. (2004). During retrieval suppression (i.e., "no-think" trials), response-override mechanisms in the lateral prefrontal cortex (green area) are engaged to reduce activation in the hippocampus (red area, in the cutaway), a structure fundamental to memory for events, thereby impairing memory for suppressed items. Although only the left prefrontal cortex and right hippocampus are illustrated, these effects occur on both sides of the brain.

Can emotionally negative memories also be controlled in this way? Recently, Depue et al. (2007) replicated the activation of the motor stopping network and the down-regulation of the hippocampus during "no-think" trials when people suppressed retrieval of aversive scenes. They also found that suppression reduced activation in the amygdala, a structure implicated in emotion processing. This suggests that suppressing recollection of unpleasant memories may also limit negative emotional responses, consistent with the involvement of memory suppression in emotion regulation. Importantly, during "no-think" trials, both the hippocampus and amygdala were not simply less engaged than they were during "think" trials, they were also less active than they were when people simply stared passively at an empty screen, suggesting that overriding retrieval involves actively disengaging these brain regions.

It appears that when people want to avoid catching their mental cacti and prevent an unwelcome reminding, they engage systems similar to those necessary for motor stopping. The difference between motor and memory control may be the cortical site influenced by control; with motor inhibition, the motor cortex is modulated, but with memory inhibition, people instead "close down memory lane" by down-regulating activation in the hippocampus (Anderson & Weaver, 2008).

INDIVIDUAL DIFFERENCES IN MEMORY SUPPRESSION

The preceding findings suggest that people suppress unwanted memories by recruiting the lateral prefrontal cortex to stop retrieval, and that doing so makes these memories harder to recall. Are all people equally effective at this? Perhaps factors known to impair executive control, such as attention-deficit/hyperactivity disorder (ADHD), damage to the prefrontal cortex, and depression, might render a person vulnerable to intrusive memories. Such deficits may contribute to persisting flashbacks associated with posttraumatic stress disorder (PTSD) or ruminative tendencies evident during depression. Do executive control deficits cause deficiencies in memory suppression?

Imaging and behavioral evidence support this hypothesis. For example, brain activity in the lateral prefrontal cortex during "no-think" trials predicts how much memory suppression each person displays (see Fig. 4; Anderson et al., 2004; Depue et al., 2007). Electrophysiological measures of brain activity yield similar conclusions. Bergstrom, de Fockert, and Richardson-Klavehn (in press) found that individual differences in memory suppression were predicted by the size of an early negative ERP effect that resembles one associated with performing a "no-go" trial and that may originate in the lateral prefrontal cortex. Similarly, behavioral measures of executive control, such as complex working-memory span, predict memory suppression (Bell & Anderson, 2005). Indeed, individuals with the poorest working-memory span showed facilitation of the to-be-suppressed memories, indicating that these participants were unable to prevent unwanted memories from intruding. Such natural variation in executive control presumably contributes to why some people are less able than others to control intrusive memories.

What about populations who have difficulties engaging executive control? Theories of cognitive development and aging often focus on how executive-control abilities change across the life span due to the late development and early decline of the prefrontal cortex. Clinically, executive deficits are thought to contribute to psychopathologies including obsessive-compulsive disorder, depression, schizophrenia, ADHD, addiction, and PTSD. Do these populations have impaired memory-control abilities? Reduced negative control effects have now been found when older adults are compared to younger adults (Anderson, Reinholz, Kuhl, & Mayr, 2009), when 8- to 9-year-olds are compared to either 10- to 12-year-olds or adults (Paz-Alonso, Ghetti, Matlen, Anderson, & Bunge, 2009), and when people suffering depression are compared to nondepressed controls (Hertel & Gerstle, 2003; but see Joorman et al., 2005). Taken together, these findings indicate that the ability to control intrusive memories develops during childhood and may be vulnerable to the effects of normal aging and clinical syndromes that affect executive function. Thus, elucidating the neurocognitive mechanisms underlying memory control has the potential to impact problems of clinical importance.

CONCLUSIONS AND FUTURE DIRECTIONS

As individuals and as societies, we alter our worlds to prevent ourselves from being reminded of experiences we would prefer

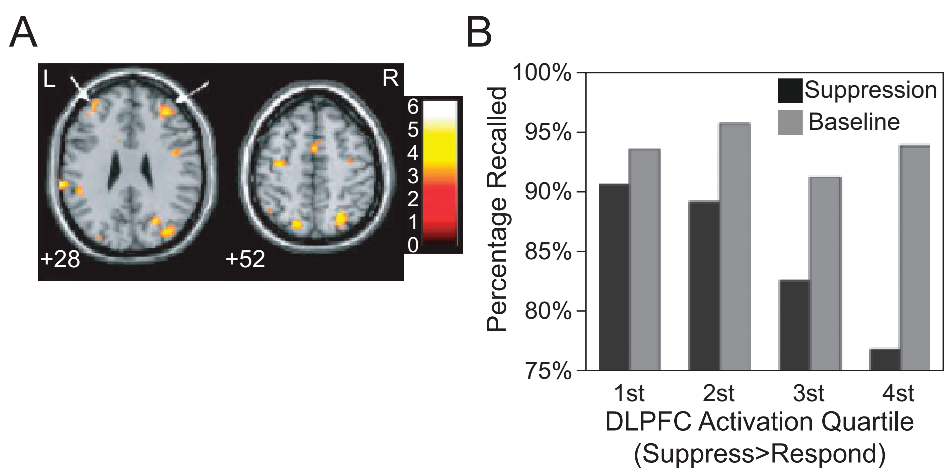

Fig. 4. Negative control effect (impaired recall of no-think items relative to baseline items) as predicted by recruitment of the dorsolateral prefrontal cortex (DLPFC). Regions plotted in warm colors in (A) are those that correlated with the magnitude of the negative control effect observed on the final memory tests (the white arrows indicate the lateral prefrontal cortex). The graph (B) shows the negative control effects for four subject groups, differing in lateral prefrontal cortex activation. Each quartile in the graph refers to a group of subjects defined by the degree to which they engaged prefrontal cortex more for "no-think" trials compared to "think" trials. Subjects who showed the largest difference in lateral prefrontal activity (i.e., the 4th quartile) showed reduced recall of "no-think" items compared to subjects who displayed smaller differences in brain activity. (The groups did not differ in their recall of baseline items.)

not to have had; we throw away photographs and objects given to us; we change apartments or towns; we even tear down buildings (e.g., the library associated with the Columbine shooting) to control what we remember. But reminders are not always escapable. When forced to live with reminders, our only choice is to modify our mental landscape—to adapt how our memories respond to reminders. In this article, we reviewed work examining how this internal adjustment occurs. People control unwanted memories in much the same way they control physical actions; they engage neural systems that evolved to inhibit habitual action, but instead target structures involved in memory. This inhibition persists, causing these avoided memories to be harder to remember later.

Although the current framework represents a good beginning, significant questions remain (Anderson & Levy, 2006). What is the fate of memories that are suppressed? Are they permanently damaged? Or do they remain in storage, dormant and ready to be recalled by future reminders? Regardless of the fate of the suppressed memory, other remnants of an experience may influence behavior. Research on multiple memory systems indicates that emotional conditioning, perceptual priming, and procedural skills rely on the amygdala, perceptual neocortex, and basal ganglia, respectively (see Squire, 1992, for a review). If suppressing unwanted memories modulates hippocampal activity, impairing episodic memories, perhaps conditioning and perceptual fluency associated with the experience remain; we may fear an object or feel familiarity for a stimulus without consciously remembering why. At present, little research has addressed these questions, even though such influences would have significant clinical implications. Moreover, other work on thought suppression has found ironic increases in the accessibility of unwanted thoughts under some conditions (Wenzlaff & Wegner, 2000). A complete understanding of how we control unwanted memories requires an account of when control leads to impaired or enhanced access (see Levy & Anderson, 2008).

For research on memory control to have its greatest impact, translational research examining its implications for clinical practice is essential. Do the networks identified here vary in efficiency in clinical populations deficient in memory control, such as those suffering from PTSD and ADHD? Can we predict who will experience intrusive memories in the aftermath of trauma based on response-override abilities? Can we develop interventions that improve control over unwanted recollections? Although it may be unwise to ask those suffering from trauma to simply suppress unpleasant memories without coming to grips with their implications, it would be similarly unwise to ignore the need to regulate intrusive memories. Under the best of circumstances, voluntary suppression will not result in a "spotless mind," and certainly would not work like a memory-deletion device. However, this slower, gradual solution to forgetting may be a graceful compromise between the desire to expel what is unpleasant from our lives and the need to retain experience to grow as individuals.

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