

Inhibition: Attentional regulation of cognition

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The term 'inhibition' has played a role in psychology and physiology since at least the mid-nineteenth century (Smith 1992). Then, as now, some used the term loosely, others tied it to operations, or to physiology (or both). Indeed, many saw inhibition as an essential process for education, mental health and moral behavior (Smith 1992, Chapter 7). Many of the great names (e.g. Morgan, Freud, Ribot, James and Wundt) associated with the origins of psychology commented on, relied on and/or criticized notions of inhibition (see Diamond *et al.* 1963, Chapter 8). In today's light, some of the early meanings attributed to inhibition are insulting (e.g. to women) and wrong headed, others however (e.g. Morgan 1891, pp. 459–461) are congruent with the concept of inhibition proposed by Hasher and Zacks in 1988 (see also Hasher *et al.* 1999; 2007).

A fundamental assumption in the view of Hasher and Zacks, a fundamental assumption is that familiar stimuli activate their representations automatically—with or without awareness—and that this massive activation (and its spread to associated representations) can and must be downregulated in order for organized behavior to achieve an individual's long- and short-term goals. This downregulation is accomplished by *inhibitory* mechanisms that operate in the service of goals.

Familiar stimuli are present in both the immediate environment and in the world of thought. Individuals are presumed, in this framework, to differ minimally in activation processes, but to differ greatly in the efficiency of inhibition—or in the ability to downregulate activation. People with generally poor inhibitory abilities will have difficulty ignoring concurrent distraction, as well as difficulty in stopping thoughts and actions that were recently relevant, but that no longer are. As well, they may have difficulty stopping thoughts tied to anticipation of events in the near future, i.e. individuals (and groups of individuals) with poor or inefficient inhibitory mechanisms will have particular difficulty living in the moment and satisfying immediate goals because their thoughts and actions are rather more under the control of the excitation triggered

by environmental stimuli and recent and future thoughts and events than under the control of their own goals.

Lapses in inhibitory regulation have a number of consequences. For one, they create high levels of distractibility, resulting in slowed and error-prone behavior. Lapses enable the production of strong but momentarily incorrect responses, as well as poor retrieval of specific events. Poor retrieval of details is the consequence of *two* inhibitory-based problems. The first occurs at encoding when poor inhibitory regulation creates memory representations (or bundles) that are cluttered with irrelevant along with relevant information. The problem created for retrieval is that searching through a cluttered memory trace results in slower and less accurate performance than does searching through an uncluttered trace. Inhibition plays a second role at retrieval. Because any cue can retrieve more than one memory representation, inhibition must suppress any nonrelevant representations that come to mind in order to conduct a search through the relevant memory bundle. That is, the downregulation enabled by inhibition is required for choice in memory retrieval (as it is in any other situation with competing options). Poor suppression at retrieval thus slows choice between activated sets of representations and, should that process be successful, poor suppression will also slow search within a selected memory bundle that contains nonrelevant representations.

On these bases, one might think that people with poor inhibitory abilities should have a great deal of difficulty achieving their goals and coping with the intellectual and social demands of their world—and some may indeed have such problems. However, it is also possible that the absence of strong inhibition can set the stage for aspects of preserved and possibly even superior cognition. For example, people who do not filter out irrelevant information during encoding will learn about that ‘irrelevant’ information tacitly and may be able to use that knowledge subsequently (e.g. Rowe *et al.* 2006). Also, greater creativity may be in part a result of reduced inhibitory regulation.

This viewpoint predicts (or postdicts) a number of reliable findings in the aging literature, including slowing, reduced working memory performance, differences in patterns of comprehension, reduced access to details about the past, poor control over strong responses, among others (see Winocur and Hasher 2002, for similarities and differences in inhibition between older humans and nonhuman animals). It is important to note with respect to human aging that not all differences between normal younger and healthy older adults (or any other groups with reduced inhibitory efficiency) should be attributed to inhibition because at least some differences may well be tied to differences in individuals’ or groups’ goals and values (e.g. May *et al.* 2005).

Healthy older adults are not the only individuals with reduced inhibitory regulation; those with mild cognitive impairment may show even greater problems, as may those with dementia. Depressed individuals and perhaps individuals with schizophrenia, with attention deficit disorder and those operating under high levels of stress may also have inhibitory deficits. Of course, there will be individual differences in the 'normal' young adult population as well. Recent neuroimaging studies with both younger and older adults have shown a relationship between the ability to suppress activation to irrelevant stimuli and the ability to remember the targets (Gazzaley *et al.* 2005).

Some have suggested that the gold standard for demonstrating inhibition is evidence of below baseline activation (where baselines vary with tasks). Such findings have been reported in both neuroimaging and behavioral studies (May and Hasher 1998; Gazzaley *et al.* 2005). It is worth noting, however, that to be effective, inhibition need not reduce activated representations to such a level, it merely needs to dampen the activation accorded to familiar or recent representations. It is this dampening that probably permits the selection of a goal-related representation in thought (or action), changes in the current contents of consciousness, the creation of boundaries between events and, ultimately, goal-driven behavior.

At a conceptual level, it is unclear whether or not there is one type of inhibition, or multiple types, each with different underlying determinants and with different age and individual difference trajectories. For example, the ability to regulate strong responses (termed *restraint* control by Hasher and Zacks, often referred to simply as 'inhibition' by others) may or may not be mediated by the same factors that underlie the ability to ignore concurrent distraction (termed *access* control) and both of these may or may not be different from the inhibition required to stop processing one topic (or to create an event boundary) and so to start another (termed *deletion* control; all terms from Hasher *et al.* 1998). All of these may or may not be different from the inhibition entailed in paradigms used by Anderson and Bjork (1994). The three mechanisms proposed by Hasher *et al.* are conceptually useful but may or may not prove to be separable at either a behavioral or a neural level.

With respect to the issue of tying behavior to underlying physiology, those connections are highly desirable now, as they were in the last century (Dodge 1926), and perhaps the goal is more attainable as well (Gazzaley *et al.* 2005). In addition to neuroimaging and animal model studies, another approach to understanding the underlying physiology is to explore performance on tasks requiring inhibitory control at peak versus off-peak times of day, on the assumption that excitatory processes are invariant across waking hours but inhibitory processes are not (Hasher *et al.* 2005). What the underlying physiology

might be is currently unclear, but some evidence suggests a focus on frontal function and on neurotransmitters that are particularly critical for frontal function and likely pathways from frontal to other regions in the brain.

No good (or bad) concept is without its critics and, in this, the concept of inhibition is in excellent company, for example with such concepts as automaticity and capacity. Included among contemporary—and nineteenth and twentieth century—criticisms of the construct of inhibition are issues such as whether or not a particular task necessitates inhibition as an explanation and the lack of a direct connection from behavior to underlying physiology.

At a purely conceptual level, inhibition is a mechanism that stops ongoing activity or that reduces the activation of one or more competitors for thought and action, thereby enabling the selection of those consistent with goals. Like many of our forebears (see Smith 1992), we view inhibition as a general attentional mechanism impacting on intellectual life broadly, ranging from memory, to choice and decision making, to language comprehension, and to creativity and problem solving. In this conception, inhibition is seen as a cognitive primitive that underlies individual, age and other group differences in the more commonly studied mechanisms of working memory and speed (see Hasher *et al.* 2007). As such, it may prove to be the (or a) key mechanism underlying general intelligence. When behavior is driven by excitation unmodulated by inhibitory control, people are likely to rely on implicitly acquired and expressed knowledge or on well-practiced behavior patterns and highly accessible constructs. Inhibition sets the stage for coherent behavior that is largely under the control of goals, rather than behavior that is under the control of passing stimuli and thoughts.

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