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The Concept of Inhibition in Cognition

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Everyone knows what inhibition is—and that creates a very real problem. The idea is so ingrained that it is difficult to discuss it as a scientific concept without contamination from existing world knowledge. Yet discussing it is exactly what cognitive scientists have been attempting to do with renewed vigor in the recent past, owing to at least three factors: the growth of cognitive neuroscience, developments in cognitive modeling, and newly described cognitive phenomena. Beginning with the phenomenon of negative priming (for reviews, see Fox, 1995; May, Kane, & Hasher, 1995; Tipper, 2001) and spurred by two influential books that appeared in quick succession just over a decade ago (Dagenbach & Carr, 1994; Dempster & Brainerd, 1995), interest in cognitive inhibition grew. Of course, the desire to mesh cognition with neuroscience also has provided a powerful impetus for understanding the place of inhibition in the current conceptualization of mind and brain. This interest is well illustrated by the inclusion of inhibition as one of only 16 core concepts in a recent effort to grapple with concepts—free of empirical research findings—that are fundamental to memory (Roediger, Dudai, & Fitzpatrick, in press).

This chapter is intended as a broad introduction to the concept of inhibition in cognition and consequently to this book as a whole. For this reason, I take no strong stand on the value of the concept (although I have expressed a skeptical point of view elsewhere; see MacLeod, in press; MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003). In this chapter, the goal is to set out the issues involved in the empirical study and theoretical understanding of the concept of inhibition as it applies to the operation of cognition. So I begin with what this chapter is and is not about. This chapter is not about the neural concept of inhibition: It is accepted that neurons certainly can inhibit each other. This chapter also is not about the physical–response concept of inhibition: It is

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accepted that actions can be initiated and then cancelled (Logan & Cowan, 1984), although the extent to which these two domains of inhibition relate to each other remains to be established. This chapter is about the concept of *cognitive inhibition*—the idea that mental processes or representations can be inhibited.

Cognitive and Neural Inhibition: Two Separate Worlds

There is one aspect of this preliminary framing that must be highlighted. The unassailable evidence for the existence of neural inhibition should be seen as in no way speaking to whether cognitive inhibition exists or, if it exists, to the form or forms that it might take: These are simply different levels of analysis that share a label, which may be responsible for more confusion than clarity. Indeed, neural inhibition at the conceptual level is likely not unitary. Cohen (1993), for example, distinguished four types of neural inhibition, each composed of a variety of neural components. Should all of these inform thinking about cognitive inhibition? Should there be four kinds of cognitive inhibition? These questions are meant to illustrate one of the problems in trying to draw a direct analogy between neural and cognitive inhibition; they are not meant to suggest that such analysis should not be undertaken or that it is doomed to fail. Rather, they are meant to encourage more concerted efforts with respect to the evidentiary and/or logical arguments for or against symmetry across levels of analysis.

With the goal of focusing attention on *cognitive* inhibition, I take one strong stand here. I strongly disagree with the common view, as stated in one of the most influential modern articles on cognitive inhibition, that

> the existence of such inhibitory mechanisms in the functional architecture of cognition seems both plausible and necessary: plausible because the substrate on which that architecture operates—the brain—uses both excitatory and inhibitory processes to perform neural computation, and necessary because computational analyses show that inhibitory mechanisms are critical for maintaining stability in neuronal networks. (Anderson & Spellman, 1995, p. 68)

Trying to force these two levels of analysis to fit together so that they can share a common term is unlikely to help advance understanding of either, a point that was made a long time ago (Breese, 1899). Indeed, it is noteworthy that even Anderson and Spellman (1995) chose to set aside one of the hallmark features of neural inhibition—its brief duration—in their argument for a much longer lasting cognitive inhibition, saying, "The strong assumption that cognitive inhibition should follow the characteristics of individual neurons receiving a single inhibitory input . . . is likely to be far too simple" (p. 95).

To reiterate, then, this chapter is about the cognitive or mental concept of inhibition, also variously called *repression*, *suppression*, or *restraining* (and sometimes even *blocking*, although *blocking* appears to have a different meaning for most investigators). For excellent histories of ideas concerning inhibi-

tion, the reader should consult S. Diamond, Balvin, and Diamond (1963) and particularly the more recent treatment by Smith (1992). As a point of departure, *The Oxford English Dictionary* (1989) lists four meanings for *inhibition.* The first two relate to the societal or legal prohibition senses and so are not relevant here. The remaining two relate to the physiological and psychological senses, consistent with the admonishment (MacLeod, in press; MacLeod et al., 2003) to keep these two senses distinct.

Focusing just on cognitive inhibition, the active ingredients appear to be primarily two: mental withholding and reduced performance. The former is an inference from the latter, reflecting a confusion that pervades the literature. In cognition, inhibition is sometimes a measurable phenomenon, sometimes a theory about the cause of that phenomenon, and often both. As always, it is a bad idea to name a phenomenon using the label for one of the possible theories that might explain it. This is not to claim that that theory is wrong, but to urge avoidance of confusion. Inhibition may—or may not—play a key role in explaining (aspects of) cognition: That is what this book is about, with the aim of considering the variety of perspectives.

A Definition of Cognitive Inhibition

How might *inhibition* be defined from a cognitive standpoint? Given its strong standing in the vernacular, the term often is not defined at all. To remedy that common oversight, I propose the following definition: *Cognitive inhibition is the stopping or overriding of a mental process, in whole or in part, with or without intention.* The mental process so influenced might be selective attention or memory retrieval or a host of other cognitive processes. Typically, this influence would not be to eradicate or entirely prevent some process from occurring but rather to slow it down or reduce its probability of taking place (relative to some neutral baseline condition or situation). Inhibition could be applied as an act of will, or it could be more automatic, perhaps as a by-product of another cognitive process. Two other features might be considered relevant: recovery and reactivity. In the present context, *recovery* means that inhibition could be permanent or could be transitory, subject to (perhaps complete) lifting under specified conditions. *Reactivity* means that inhibition may be applied to the extent that it is required under the circumstances (i.e., it may not be all or none), an idea that goes back to Wundt (1902) but one that if not embedded in a formal theory may give too much flexibility to the concept.

Because inhibition is so rarely explicitly defined, my definition is certain to be challenged, but at least it provides a starting point. Indeed, some of the confusion apparent in the literature could be eliminated if each investigator would explicitly define what he or she means by inhibition. My strong sense is that this practice would quickly demonstrate that the term has a wide range of meanings and that at the very least, some kind of framework for a theory of inhibition is required. The definitions offered in chapters 6, 8, 9, and 14 of this volume help to underscore this point. In this regard, attempts at offering empirical criteria for the demonstration of inhibition (e.g., Anderson & Bjork,

1994) should certainly be encouraged, a point that is amplified later in this chapter.

Cognitive Inhibition Beyond Cognition

The concept of cognitive inhibition in mainstream cognitive psychology is permeating all of the other traditional areas of psychological inquiry as well (e.g., developmental, social, clinical). This concept—sometimes it is more of a metaconcept—is a powerful one and hence a seductive one. For this reason, it is useful to illustrate this broader research perspective before homing in on mainstream cognitive research. Certainly, the tasks and approaches developed within cognitive psychology, as well as the theoretical principles to which those tasks and approaches become linked, are influential not just in the study of cognition but throughout the discipline. In the next sections I illustrate several subareas, each with a single study, although numerous other published studies could have been selected.

Developmental Psychology

O. Friedman and Leslie (2004) explained children's performance in the false belief task as relying on a critical inhibitory process (for related ideas, see Carlson & Moses, 2001; Russell, Mauthner, Sharpe, & Tidswell, 1991). In a variation on the standard version of this task, children are told about a girl, Sally, who sees two boxes, one red and one blue, and then sees a frog placed under the red box. After Sally leaves the room, the children see the frog moved under the blue box. The critical question asked of the children is where Sally thinks the frog is or where Sally will look for the frog. Given that Sally did not see the frog switch boxes, the correct answer is the red box (where the frog initially was) and the incorrect answer is the blue box (where the frog now actually is). Somewhere between ages 3 and 4, children shift from the incorrect to the correct answer (for a review, see Wellman, Cross, & Watson, 2001)—from relying on what they themselves saw to taking the perspective of what Sally knows.

O. Friedman and Leslie (2004) argued that the inhibition of competitors is fundamental to the selection among alternative beliefs, akin to the selection-by-inhibition explanation of negative priming in the attention literature (for a review, see Tipper, 2001). They theorized that for children to succeed, the most salient box—the blue one, because that is where the children know the frog actually is—must be inhibited. What the 4-year-old can do that the 3-year-old cannot is successfully apply the inhibition. O. Friedman and Leslie went on to provide an elegant test of their inhibition theory in a considerably more complex version of the false belief task, but describing this would take us too far afield. They concluded that "competent reasoning about beliefs depends on the development of inhibitory control" (p. 552). This emphasis on inhibition in understanding development is not unique to O. Friedman and Leslie (see, e.g., Bull & Scerif, 2001; A. Diamond, Kirkham, & Amso, 2002; Wilson & Kipp, 1998; see also chap. 13, this volume).

Social Psychology

A major question in social psychology is what causes a stereotype to come to mind (activation) and to influence one's impression (application) when one comes in contact with a member of the stereotype-relevant group. Kunda and Spencer (2003) proposed that the activation of stereotypes is driven by three goals. First is the goal of comprehension—simplifying and understanding the situation. Second is the goal of self-enhancement—the nurturing of self-esteem. Third is the goal of avoiding prejudice—either to see oneself as egalitarian or to comply with egalitarian social norms. The comprehension and self-enhancement goals function similarly: As the strength of the goal increases, often the likelihood of stereotype activation and application increases as well. The stereotype simplifies interpretation of the situation and maintains or even enhances self-esteem.

What makes the Kunda and Spencer (2003) framework unique is the emphasis on inhibition. They argued that it is also possible that a stronger goal will lead to inhibiting the stereotype. So for comprehension, when information about the specific individual is available, it may be better to inhibit the stereotype and instead use the individuating information. For self-esteem, if one is motivated to form a positive impression of an individual, it may be better to inhibit the (negative) stereotype. In the case of the goal of avoiding prejudice, the primary process may in fact be inhibitory, acting to suppress the negative stereotypic information. Kunda and Spencer suggested that the application of inhibition may be cognitively demanding and may become more likely to fail as cognitive resource demands increase. Such an emphasis on inhibition in understanding social processes is not unique to Kunda and Spencer (see, e.g., Beer, Heerey, Keltner, Scabini, & Knight, 2003; Förster, Liberman, & Higgins, 2005; Shah, Friedman, & Kruglanski, 2002; von Hippel & Gonsalkorale, 2005; see also chap. 7, this volume).

Clinical and Personality Psychology

Many illustrations are possible in the domain of clinical and personality psychology, but I describe only one. Wood, Mathews, and Dalgleish (2001) asked subjects who were either high or low in trait anxiety to make decisions on each trial about whether a single target word was or was not related to the sentence that preceded it. Sentences were constructed in pairs, differing only in the final word, an example being "At the party she had some punch/wine," where the first of the two possible final words was a homograph. The task was to determine whether the probe word *fist* was semantically related to the sentence. The answer should have been no in both cases, but critically, *fist* is related to the other sense of the homograph *punch*. Therefore, failure to suppress that other sense would slow rejection of *fist*. The prediction was that such a failure to inhibit would be more likely in high-anxiety subjects.

In their first experiment, Wood et al. (2001) found that all subjects were faster to reject the probe *fist* in response to *wine* than to *punch* but that there was no effect of anxiety level. This finding might seem to conflict with their

prediction, but in their second experiment, when subjects were under higher cognitive load because they had to rehearse a set of digits during task performance, the pattern changed. Anxious subjects showed a pattern suggesting a general impairment of inhibitory processing. Wood et al. concluded that "anxiety-prone individuals have a deficit in tasks requiring the inhibition of currently irrelevant meanings" but that this impairment "may be revealed only when task-related control strategies are limited by mental load" (p. 176). This emphasis on inhibition in understanding personality and abnormal behavior is not unique to Wood et al. (see, e.g., Bohne, Keuthen, Tuschen-Caffier, & Wilhelm, 2005; Dorahy, Middleton, & Irwin, 2005; Kuhl & Kazén, 1999; see also chaps. 10, 11, and 13, this volume).

Behavioral Neuroscience

Colvin, Dunbar, and Grafman (2001) contrasted patients with frontal lobe lesions with normal subjects performing a water jug task (Luchins, 1942). In the version of the task that they used, subjects had to manipulate three jugs with known capacities (A = 8 units, B = 5 units, C = 3 units) to reach a specified goal state (A = 4 units, B = 4 units, C = 0 units). Patients, particularly those with left dorsolateral prefrontal lesions, performed poorly, especially when they had to make a counterintuitive move—one that resulted in a step back from the goal state and therefore was not predicted by a simple means–end analysis without planning. In particular, patients tended to prefer to go back to an earlier state rather than to make a counterintuitive move. Colvin et al. argued that intact functioning of the left dorsolateral prefrontal region is necessary in part for "the inhibition of a response generated by an adopted problem-solving strategy" (p. 1138). Of course, this emphasis on inhibition in understanding behavior from a neuroscientific perspective is certainly not unique to Colvin et al. (see, e.g., Amos, 2000; Durston et al., 2002; Gazzaley, Cooney, Rissman, & D'Esposito, 2005) and is in fact very much in the zeitgeist in this domain.

Inhibition in Cognition

In the preceding section, the goal was to indicate the breadth and current impact of the concept of inhibition as an explanatory element in traditionally recognized subdomains of psychology other than cognition. Much of this impact can be placed at the doorstep of cognition, in that the tasks and explanations in these domains have often been modified from cognitive antecedents. Let us turn now to cognition itself, where the growth of explanations involving inhibition has been dramatic in the past 25 to 30 years since research on negative priming began to lead the charge.

All of the illustrations in the preceding section are instances where cognitive inhibition has been proposed as a key mechanism in explaining observed behavior. It is fair to say that the concept is by now ubiquitous, having been applied to, among other cognitive activities, action, language, meaning, mem-

ory, perception, responding, thought, and working memory. Without doubt, it is a compelling idea, one that lends considerable power to theory—not to mention the seductive draw of the neural analogy. It seems, in fact, that cognitive inhibition *has* to exist: In James's (1890) words, "Inhibition is a *vera causa*, of that there can be no doubt" (p. 67). Even more to the point is what Mercier (quoted in Smith, 1992) said a couple of years earlier, in 1888: "If [inhibition] did not exist it would be necessary to invent it" (p. 21).

In the early days of psychology, the concept of inhibition was prevalent and influential (e.g., Breese, 1899; Pillsbury, 1908; Wundt, 1902). However, it largely disappeared as a theoretical entity in the face of behaviorism and even through the early growth of cognitive psychology, relegated to terms describing empirical phenomena such as *conditioned inhibition* and *proactive inhibition*. Then, about 30 years ago, it began to reappear with theoretical impact in research on the phenomenon initially given several names (e.g., *distractor suppression*) but ultimately called *negative priming* (Lowe, 1979; Neill, 1977; Tipper, 1985). Wundt (1902) had argued that to attend to one of several simultaneous stimuli, the others had to be inhibited. This idea was revived to explain negative priming, and a strong paradigm–theory linkage quickly developed.

Attention

In negative priming experiments, each trial typically involves two stimuli, one to be attended and one to be ignored. If the ignored stimulus on one trial becomes the target stimulus on the next trial, responding to it is slower than would have been the case if the previous trial were completely unrelated. The argument originally put forward by Neill (1977; for an updated view, see chap. 4, this volume) and championed by Tipper (1985, 2001) was that the ignored stimulus was inhibited to permit the target stimulus to control responding. Then, when that ignored stimulus itself became the target, the inhibition just applied to it had to be overcome for it to control responding, and this process took additional time.

This apparently simple task, with its intuitively appealing explanation, was quickly followed in the attention literature by the phenomenon of inhibition of return (Posner & Cohen, 1984). The prototypical procedure consists of three outline boxes with subjects instructed to fixate on the center box and to move only their attention (not their eyes) during the trial. Then one of the two peripheral boxes brightens, drawing attention to that cued location despite the cue not being informative. Shortly thereafter, a target appears. When the time between cue and target is brief, target detection is faster at the cued location—the intuitive pattern of automatic capturing of attention by the cue. However, when the cue–target interval is longer than 300 milliseconds, detection is slower at the cued location. As the term *inhibition of return* was intended to suggest, attention may be inhibited from reorienting back to the cued location, resulting in delayed or slower processing there (e.g., Rafal, Egly, & Rhodes, 1994; Reuter-Lorenz, Jha, & Rosenquist, 1996).

Much research has followed in which inhibition has been proposed to play a key role in attentional processing (e.g., task switching in Allport, Styles, &

Hsieh, 1994; visual marking in Watson & Humphreys, 1997; see also chaps. 2–4, this volume). The nature of that role, however, appears to be broad, leading to the question of what these various forms of inhibition have in common. Are there common processes or at least a small set of crucial processes? Such a limitation would seem to be important for the concept of attentional inhibition to be coherent and parsimonious. Efforts have been made to address this question. Thus, Rafal and Henik (1994) distinguished three inhibitory processes. The first is inhibition of responding to signals at unattended locations, the kind of process involved in spatial versions of negative priming. The second is endogenous inhibition of reflexes, more akin to stopping a prepotent response. The third is reflexive inhibition of the detection of subsequent signals, the kind of process involved in inhibition of return. The glue that links these processes together as inhibition remains elusive, but that certainly does not mean that such a linkage cannot or will not be accomplished as research progresses.

Turning to the neural level, there is also evidence consistent with attentional inhibition operating at intermediate levels of cortical processing, in visual area V4 and in TEO (the posterior portion of the inferior temporal cortex). Attention may work in a push–pull fashion to promote processing of what is attended and to inhibit processing of what is unattended (for a review, see Kastner & Pinsk, 2004). This push–pull idea is also familiar as *center-surround* and goes by other names as well. The extent to which this idea relates directly to cognitive inhibition must be clarified, but the connection is unquestionably appealing.

Memory

The employment of inhibition as an explanatory tool is no less prominent in memory than it is in attention. This emphasis began with the work of Hasher and Zacks (1988; see also chap. 8, this volume) focusing on the cognitive costs associated with aging and bridging the attention–memory gap. Like Rafal and Henik (1994), Hasher and Zacks described three components of inhibition, all seen as influencing the optimal operation of working memory (via attention): (a) control of the specific information that enters working memory, (b) control of the information that is deleted from working memory, and (c) prevention of possibly relevant but incorrect responses from being executed. Their argument, based on an extended series of studies, is that older people do not execute these functions as well as younger people because older people do not inhibit as well. Their research program has made a concerted effort to characterize these proposed processes, and their account has been influential (for review and commentary, see Burke, 1997; McDowd, 1997; for other views, see chaps. 9 and 10, this volume). The Hasher and Zacks inhibition-based account of aging has not been without critics, however: As Charlot and Feyereisen (2005) concluded in their review concerning executive control and prefrontal cortex, "The changes tied to cognitive aging in the domain of episodic memory cannot be uniquely explained by a deficit in inhibition" (p. 349, my translation).

Next to the work of Hasher and Zacks (1988), the most visible work arguing for inhibitory processes in memory is that of Anderson and colleagues (Anderson, 2005; Anderson & Green, 2001; Anderson & Spellman, 1995). Anderson and Spellman (1995) had subjects learn an initial list of category–instance word pairs and then practice half of the items in half of the categories. They found that the unpracticed half of a category was actually more poorly remembered than a corresponding half from a category in which no items were practiced. Moreover, not only were the unpracticed items less accessible from their studied cues, they were also less accessible from independent semantically related probes. It appeared that these unpracticed items had become generally less accessible, a pattern consistent with their representations having been inhibited.

Anderson and Green (2001) went on to develop a clever variation on this paradigm that they referred to as the "think/no think" paradigm. After studying a list of pairs, participants were asked to try not to think of a previously studied word when provided with a cue that had been studied with that word. Having tried not to think of a word resulted in poorer recall than in the control condition, where studied pairs were neither thought of nor suppressed. Moreover, the target word was also less likely to be recalled to a semantic cue that had not been studied: It appeared that the target word itself, not just the studied pair, was inhibited as a result of not thinking about it. This cue independence has been seen by Anderson and Green as the strongest evidence of inhibition being involved in memory.

There are many other illustrations of inhibitory accounts applied to memory phenomena. Anderson (2005) pointed to the related paradigm of directed forgetting (for a review, see MacLeod, 1998), in which it has been argued (Basden, Basden, & Gargano, 1993) that when the first half of a list is followed by an instruction to forget, it is more poorly remembered than the second, to-be-remembered half of the list because it has been inhibited. Similarly, when subjects are provided with a partial set of members of a studied list to aid the retrieval of the remainder, this typically hurts rather than helps performance—the part-list cuing effect (Slamecka, 1968). Bäuml and Aslan (2006) argued that this effect is, at least under certain conditions, due to inhibition of retrieval. There are certainly plenty of other illustrations of memory phenomena held to be at least in part attributable to inhibition (see, e.g., Brown, Zoccoli, & Leahy, 2005; Racsmány & Conway, 2006; Veling & van Knippenberg, 2004).

In the memory literature, another way of examining inhibition has been prominent—that of individual differences. Two different approaches have been taken—that of Engle and his colleagues and that of N. P. Friedman, Miyake, and their colleagues. Engle and his colleagues (Conway & Engle, 1994; Engle, Conway, Tuholski, & Shisler, 1995; Kane & Engle, 2000) put forth a perspective related to that of Hasher and Zacks (1988) in that it also emphasizes attentional resources and working memory, although Engle's emphasis on general capacity distinguishes his view from theirs. Conway and Engle (1994) argued that a major source of individual differences in cognitive ability is the capacity of working memory and that these individual differences result from variation in attentional resources that in turn produce "differences in the ability to

inhibit or suppress irrelevant information" (p. 354). The impact of these differences should be evident in controlled tasks requiring attention but not in more automatic tasks. Redick, Heitz, and Engle (chap. 7, this volume) have carried forward this work.

N. P. Friedman, Miyake, and their colleagues (N. P. Friedman & Miyake, 2004; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000) have taken the more psychometric approach of seeking patterns of correlations between cognitive measures. Thus, when N. P. Friedman and Miyake (2004) directed this approach to examining inhibition, they administered an extensive battery of tasks, several of which were seen as markers for each of three key inhibitory abilities: prepotent response inhibition (e.g., Stroop task, stop signal task), resistance to distractor interference (e.g., Eriksen flanker task, word naming with distraction), and resistance to proactive interference (e.g., Brown–Peterson task, cued recall task). Via structural equation modeling, they found the first two inhibitory abilities to be closely related but the third to be clearly separate, suggesting to them that the overall "trait" of inhibition was not unified. More recent work (N. P. Friedman et al., 2006) has suggested that, unlike updating working memory, which is related to intelligence, inhibiting prepotent responses (and shifting mental sets) is not.

Turning to the neural level, again multiple approaches have been taken. Hamilton and Martin (2005; see also chap. 12, this volume) presented a case study of a participant with left inferior frontal damage in which the pattern of task dissociation across a series of inhibition tasks seemed incompatible with a single shared neural substrate. Their work simultaneously supports that of Miyake et al. (2000) and N. P. Friedman and Miyake (2004)—in showing dissociations across proposed inhibitory abilities—and conflicts with it—in showing dissociations within abilities that the Miyake group held to be single abilities. Hamilton and Martin suggested that one fruitful direction to pursue would be to consider that variations might hinge not on common brain areas but rather on common patterns of neurotransmitters, such as dopamine and norepinephrine, which may influence how different brain areas operate. The puzzle of the diversity of brain areas involved in some ability might then be resolved by the commonality in the neurotransmitters affecting these areas. This is an intriguing idea, although it also highlights the fact that cognitive neurotopology may be even more complicated than currently viewed.

Gazzaley et al. (2005) used functional magnetic resonance imaging (fMRI) to examine how aging affects what they saw as a goal-driven mechanism in support of attention and memory that enhances and suppresses the processing of sensory information. On each trial, participants watched two faces and two scenes in random order and tried to remember one type of stimulus or the other for a subsequent recognition test; the control was passive viewing without the memory instruction. Like younger adults, older adults showed enhanced cortical activity for task-relevant representations; unlike younger adults, older adults were deficient in suppression of cortical activity for task-irrelevant representations. Gazzaley et al. saw their results as indicating that the inhibitory function was deficient in the older subjects but that the enhancement function was unaffected by aging, which fits nicely with the Hasher and Zacks (1988) theory (although Gazzaley et al. did note that their results could reflect excita-

tion and inhibition or simply different levels of excitation, an issue that is at present difficult to resolve in fMRI research).

Anderson et al. (2004), also using fMRI, investigated neural activity in the Anderson and Green (2001) think/no think paradigm. They first reported obtaining the same behavioral data pattern as reported by Anderson and Green—poorer memory for no-think items both in response to their studied cues and, importantly, in response to independent probes. Neural differences were evident in reduced hippocampal activation and increased dorsolateral prefrontal activation for the no-think items. They saw their results as supporting the existence of active cognitive inhibition at the neural level. Thus, there have recently been a number of quite concerted efforts to demonstrate brain parallels of cognitive inhibition in memory. This domain of research is likely to be very influential in determining the role of inhibition in cognitive processing.

Beyond Attention and Memory

In the domain of intelligence, where presumably cognitive processes are assembled and orchestrated, inhibition has also been proposed to be a fundamental component. Dempster (1991) reviewed the relation between measures of intelligence and of inhibition across a broad age range and concluded that "intelligence cannot be understood without reference to inhibitory processes" (p. 157). Although at odds with the conclusions of N. P. Friedman, Miyake, and their colleagues (N. P. Friedman & Miyake, 2004; Miyake et al., 2000), Dempster's conclusion is consistent with the findings of Salthouse, Atkinson, and Berish (2003) that in older adults, measures of inhibition correlated well with measures of fluid intelligence (although Salthouse et al. were not convinced that inhibition represented a distinct executive control function).

There is no way to do justice to the breadth and diversity of cognitive research invoking inhibition as an explanatory construct. So, like the preceding discussion of research outside cognition, this survey has been only cursory, the goal being to illustrate some of the key areas across cognition where inhibition has played a central role in the explanation of empirical findings. That role continues to grow. In the remainder of this chapter, the goal shifts to consideration of the concept of inhibition as an explanatory entity in cognition and to identifying some of the questions that must be addressed.

Four Conceptual Issues

The following section outlines in brief form four of the key issues related to understanding cognitive inhibition as a theoretical construct: definition, relation to neural inhibition, relation to interference, and measurement and the baseline problem.

Definition

When applied to cognition, the term *inhibition* definitely does not have a consistent meaning. Many scholars have recognized this, as two recent quotes and

a less recent one demonstrate. Conway and Engle (1994) said, "Unfortunately, the term *inhibition* is a nebulous one that connotes a multitude of meanings" (p. 368); N. P. Friedman and Miyake (2004) similarly observed, "These results suggest that the term inhibition has been overextended and that researchers need to be more specific when discussing and measuring inhibition-related functions" (p. 101). Slipping back a century, Breese (1899) said, "Inhibition is a term which has been used to designate all kinds of mental conflict, hesitation and arrest" (p. 14). The first charge for theorists, then, is to provide their own meaningful definition of the term so that it can be compared with other definitions, permitting debate about the "proper" definition of the term and what it entails. In my reading of the literature, the default is to not define the term and to assume that all researchers share the same meaning. They do not. It is for this reason that I offered a possible definition early in this chapter.[1]

Relation to Neural Inhibition

At the outset of this chapter and elsewhere (MacLeod, in press; MacLeod et al., 2003), I have argued that there is no necessary relation between cognitive inhibition and neural inhibition. These are different levels of analysis, and my speculation is that theorists will ultimately abandon the desire to force these two conceptual entities to become one. Just as activation in cognition is supported at the neural level by the coordination of excitation and inhibition, the same is likely to be true of inhibition in cognition should researchers choose to incorporate cognitive inhibition in explaining aspects of performance. I hasten to note that rejecting this link in no way impugns the concept of cognitive inhibition: I am not arguing that cognitive inhibition cannot be theoretically useful (or empirically demonstrated) if it is not directly linked to neural inhibition. I am arguing, in fact, the contrary—that determining the value of the concept of cognitive inhibition will be a more attainable goal if researchers avoid the confusion of trying to relate it to its nominal counterpart in the nervous system.

Relation to Interference

It is not uncommon now, nor was it in the past, to use the terms *interference* and *inhibition* interchangeably; indeed, Stroop (1935) noted this tendency in the first sentence of his famous article. But this practice unquestionably results in misunderstanding. Instead, it would be preferable to reserve the term *interference* for an empirical phenomenon in which performance decreases (relative to a suitable baseline) because of processing of some at least nominally irrelevant information. Then the term *inhibition* would be preserved as one theoretical mechanism that could potentially explain that interference. Yoking these

[1] Also to be handled with caution is the term *cognitive control,* which has crept into widespread usage and of which inhibition is often characterized as a subset. What *cognitive control* means is also in need of more rigorous definition and consideration; otherwise, it is in danger of meaning nothing more specific than *processing* or even *cognition.*

two terms tends to wed the interpretation to the phenomenon. MacLeod et al. (2003) addressed this point in more detail, and Klein and Taylor (1994) put it very well: "There is a danger of circularity whereby investigators attribute interference effects to inhibition and subsequently define inhibition on the basis of behavioral interference" (p. 146).

Measurement and the Baseline Problem

Even the term *interference* can be theoretical, implying a competition between two stimuli or two dimensions of a stimulus. For this reason, at the empirical level, the terms *cost* and *benefit* seem preferable, reflecting a deviation from some neutral condition that must then be explained (see Jonides & Mack, 1984; Posner, 1978). An observed cost might or might not be attributable to inhibition (or indeed to interference). However, this consideration pushes the problem back a level empirically, and it is an important level to consider. Observing an empirical cost in performance hinges on the neutral condition used. As always, one of the greatest problems faced by the experimental psychologist is selecting the appropriate neutral condition from the myriad possibilities. It is problematic to assume that a deflection below baseline is a straightforward reflection of inhibition, both because the baseline is always subject to debate and because other mechanisms could be solely responsible, or jointly responsible with inhibition, for the observed cost.

Five Conceptual Questions

Many of the conceptual issues that have been raised in this chapter and will be raised throughout this volume apply to other concepts in cognition just as they apply to cognitive inhibition. In holding cognitive inhibition to a high standard, my intention is not that it should be singled out in that regard. What follows is a set of questions that need to be addressed with respect to inhibition as a theoretical mechanism in cognition; these questions are, of course, not restricted to inhibition.

Use of the Concept

First, how is the concept of inhibition being used inside and outside cognition? Much of this chapter has been devoted to illustrating the use of inhibition as a theoretical mechanism both in cognition and in psychology more broadly, so a beginning has been made on this question at least at one level. However, there is another way to answer this question—in terms of the overall use of the concept. The answer is, in a word, broadly. Inhibition appears to mean different things to different investigators and theorists. Perhaps inhibition is the superordinate for a set of inhibitory subordinates, but if so, this taxonomy is in need of considerable development. The fact that the use of the term is so broad has implications for researchers' thinking about the concept and leads directly to the second question.

The Idea of a Domain-General Central Concept

Second, is there a "domain-general" central concept? The issue is whether there is conceptual coherence within and across domains—whether there is a core concept of inhibition. The analysis in this chapter (see also MacLeod, in press; MacLeod et al., 2003) suggests that inhibition at present is not a coherent theoretical entity. Once again, I note that this is in no way the death knell for the concept of cognitive inhibition. In fact, there is some agreement: Generally, the blocking sense of inhibition is not being invoked; it is, rather, the suppression (or restraint) sense that is emphasized. How that suppression operates is not well defined in many cases, however. As a result, inhibition is a concept in the same way as encoding or retrieval are concepts—at too high a level to have value as an actual processing explanation. Of course, one could certainly argue that a central concept is not necessary (or perhaps even important) and that inhibition is still a useful concept in cognition, albeit one in need of refining.

In this regard, there have been efforts to capture what is meant by inhibition, including the work of Hasher and Zacks (1988) and Rafal and Henik (1994) discussed earlier in this chapter. As another instance, Nigg (2000) proposed four kinds of inhibition, three related to cognition—executive inhibition, automatic inhibition of attention, and motivational inhibition—and the fourth more tied to psychopathological variation in these cognitive kinds of inhibition. His "executive inhibition" includes controlling inhibition due to competition, suppressing irrelevant information, and suppressing highly likely responses, all reminiscent of the three types of inhibition put forth by Hasher and Zacks. A fourth type listed under "executive inhibition" by Nigg—suppressing reflexive saccades—when coupled with the two types that he lists under "automatic inhibition of attention"—suppressing recently examined stimuli and suppressing unattended information—closely resemble the set suggested by Rafal and Henik (1994).

This convergence of theory is clearly good, linked as it is to a strong empirical base. Such efforts certainly help researchers to think about the concept, although it is reasonable to keep in mind the caution by N. P. Friedman and Miyake (2004) that "theories positing inhibition as a unifying mechanism or theme may be overly ambitious" (p. 128). What is needed is a convergence of empirical findings on each of the multiple kinds of inhibition—a goal that researchers are vigorously pursuing—as well as a theory, ideally a formal theory, specifying how to link these kinds of inhibition together and what it is that they share that makes them all inhibition.

Criteria for Behavioral Evidence

Third, what criteria must behavioral evidence fulfill to justify a claim of having demonstrated inhibition? This question is one to be emphasized, given that empirical phenomena involving behavioral costs are the wellspring of heightened interest in inhibition as an explanatory mechanism. I have suggested (MacLeod, in press) that only two criteria have been identified. The first is a reversal from a benefit to a cost over a short period of time, as in inhibition of

return in the attention literature, but there is ongoing debate as to whether inhibition actually plays a role in inhibition of return (see, e.g., MacLeod et al., 2003). The second criterion is a cost associated with an independent cue, as in the retrieval-induced forgetting and think/no think paradigms from the memory literature; I will consider this more in a moment. One might also include a third index—the switch in instructional status from being ignored to being attended, as in negative priming—but that, too, has been questioned as diagnostic of inhibition (see, e.g., Egner & Hirsch, 2005; MacLeod et al., 2003; Neill & Mathis, 1998). Although certainly useful at this juncture, these criteria are neither definitive nor sufficient.

The independent cue is so far the most compelling criterion for demonstrating that an effect is attributable to inhibition. Certainly, Anderson and his collaborators replicated the effect in numerous studies using both the retrieval-induced forgetting and think/no think paradigms (for reviews, see, e.g., Anderson, 2003, 2005; see also chap. 5, this volume). Other laboratories (e.g., Camp, Pecher, & Schmidt, 2005; Saunders & MacLeod, 2006) also have replicated the effect in retrieval-induced forgetting, but others have not (e.g., Williams & Zacks, 2001). Although there are as yet no published replications by other laboratories of inhibition to independent cues in the think/no think paradigm (but see Bergström, Richardson-Klavehn, & de Fockert, 2006), there is again a failure to replicate (Bulevich, Roediger, Balota, & Butler, in press). The meaning of these limitations should be a focus of ongoing research given the present centrality of the independent cue criterion for inhibition.

One of the goals of theorizing in providing a guide to empirical research must be to set out criteria for a behavioral phenomenon to be seen as involving inhibition. What would be especially praiseworthy would be a set of criteria that could each be applied to a given empirical phenomenon, providing conceptual convergence. Although the extant research has focused heavily on the independent cue evidence, Anderson and his colleagues have made a concerted effort to identify other criteria (see Anderson, 2003; Anderson & Bjork, 1994; see also chap. 5, this volume). Still, it would be most impressive to see further efforts and to have these jointly lead to a set of well-tested and widely accepted criteria. Finally, testing well-specified models is, as always, a most promising avenue for ascertaining the viability of concepts such as inhibition, because implemented models require that these concepts be rigorously specified (see, e.g., chaps. 6 and 14, this volume).

Accounting for Other Phenomena

Fourth, what does inhibition account for that is not or cannot be explained by other existing processes or mechanisms? This can certainly be read as a loaded question. My intention, however, is to point out that researchers need to carefully consider other possible mechanisms, particularly those already carrying substantial theoretical loads elsewhere, whenever they consider inhibition as a possible explanation. Of course, this admonition must be a two-way street and serves to highlight that inhibition should also be given fair consideration when other explanations of behavioral costs are being considered. Generality and parsimony have their place in this evaluation.

Another factor that warrants consideration in this evaluation is whether there are any "hidden layers" in an explanation. In the case of inhibition, the idea sometimes depends on an inlaid resource/capacity theory, which is itself often vague (for more on this issue, see, e.g., Hasher & Zacks, 1988; Logan & Zbrodoff, 1999; McDowd, 1997). It is important, therefore, to examine carefully the assumptions underlying an account in terms of inhibition. Adding inhibition to activation provides a powerful—possibly too powerful—theoretical framework, which may well be capable of explaining any observed pattern of data as well as its opposite. It often is difficult to enumerate the free parameters, but it is important to do so. Ultimately, only formal models are likely to be successful in this regard, so it is important to develop these in the context of inhibition. Again, inhibition is no more to be criticized than are many other cognitive constructs, but its ubiquity demands concise theory.

Plausible Alternatives

Finally, what are (some of) the plausible alternatives to inhibition? The previous question feeds directly into this last question: If not inhibition, then what? Inhibition seems to fit certain phenomena—negative priming and inhibition of return spring to mind—exceptionally well, and the list could certainly be longer. Are there mechanisms with equivalent span and intuitive appeal that provide worthy theoretical adversaries? At the level of any individual research project or even at the level of a single phenomenon, there no doubt are, and this returns us to the third and fourth questions. More globally, however, are there processing accounts that can do the same theoretical work as inhibition?

In the context of negative priming, Neill (see, e.g., Neill & Mathis, 1998) argued for what he described as an episodic retrieval view, a view derived from Logan's (1988, 2002) instance theory of automaticity. The idea is that people routinely check their memory for relevant information that might help with current processing. This checking is usually beneficial, reducing reliance on working out algorithms. Instead, the information provided by memory can simply be used to determine what to do in the present. Sometimes, however, especially in the creative tasks that cognitive psychology is known for developing, the information from memory conflicts with the information presently in the world, demanding resolution of this conflict. Making such a decision takes additional time, and so there is a behavioral cost.

In negative priming, memory indicates that this stimulus should not be responded to (because of its fate on the previous trial), whereas the perceptual display indicates that this stimulus is the response-relevant target (on the current trial). Resolving this conflict takes time that manifests as a cost. Thus, under this episodic view, it is not the inhibition of the previously ignored stimulus that slows its current processing, which is the most common explanation of negative priming. Evidence exists that favors this "automatic retrieval plus conflict resolution" (e.g., Egner & Hirsch, 2005; MacLeod, Chiappe, & Fox, 2002), although there is certainly evidence consistent with the inhibition account as well (see, e.g., Tipper, 2001).

As always, it is important to recognize the competing accounts and then to put them to critical test. It may also be that these two accounts are both

correct, but for different situations. If this possibility can be convincingly shown, it would help researchers to understand the limitations of both sets of processes. The same applies to other possible theoretical framings that also handle the patterns captured by inhibition and by episodic retrieval and that may come forward as the empirical basis and conceptual understanding deepen.

Conclusion

Inhibition at the cognitive level is a powerful theoretical construct. It has come into widespread usage in the past quarter century in part because of this power and in part because of its apparent linkage to its neural cognate. One purpose of this chapter has been to illustrate this wide usage; another purpose has been to question the value of the neural linkage. The main purpose of this chapter, however, has been to set out the issues that researchers need to grapple with as they try to ascertain the utility of inhibition—and its competitors—in explaining the operation of the cognitive system (see also chap. 15, this volume). The success of this goal hinges on more explicit definition and better criteria, on the development of more formal theorizing about inhibition, and on the discovery of new phenomena that call for inhibitory mechanisms. As the rest of this book ably demonstrates, this work is well under way. Researchers will undoubtedly learn a great deal more about the place of inhibition in cognition over the next decade.

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