Inhibition in Attention and Aging

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The literature on inhibition and aging has grown steadily in the wake of Hasher & Zacks' (1988) inhibitory deficit theory of cognitive aging. Not all of the findings support the notion of an age-related inhibitory decline, and some refinement of the theory is now required. This article has three goals: (a) to evaluate the role of inhibitory mechanisms in selective attention and aging; (b) to provide an evaluation of inhibition as a theoretical concept in theories of cognitive aging, with a specific focus on attention and aging; and (c) to consider the more general problem of evaluating progress in theory development.

A CONCEPTUAL framework for understanding age differences in working memory based on reduced inhibitory efficiency among older adults was proposed by Hasher and Zacks in 1988. In their view, the functional capacity of working memory is reduced with aging because less efficient inhibitory processes fail to prevent irrelevant information from entering or being maintained in working memory. The presence of this irrelevant information in working memory results in poorer encoding, retrieval, and comprehension on the part of older adults. In addition, declining inhibitory prowess may be responsible for many of the age-related changes in cognitive function that are described in the literature. They state that "Existing evidence in the cognitive gerontology literature suggests that the behavior of older adults is consistent with the expectations that stem from a diminished inhibition view" (Hasher & Zacks, 1988, p. 216).

Hasher and Zacks' new conceptual framework produced a marked increase in the number of studies examining inhibitory function in older adults. These studies have addressed inhibition in a variety of cognitive domains, including language, reading, memory, attention, and working memory; many of the findings have been reviewed elsewhere (e.g., Burke, 1997; McDowd, Oseas-Kreger, & Filion, 1995; Stoltzfus, Hasher, & Zacks, 1996). This review addresses the basic tenet of the inhibitory framework for understanding cognitive aging, which is that "the efficiency of the inhibitory processes that underlie selective attention is reduced" in aging (Hasher & Zacks, 1988, p. 219). The subsequent claim that "Taken as a whole, the evidence for the inhibition view (in cognitive aging) is encouraging" (Stoltzfus et al., 1996, p. 77) will be challenged, and the adequacy of the inhibitory deficit assertion for understanding selective attention in aging will be examined. Thus, the present review has three goals. The first is to evaluate the role of inhibitory mechanisms in selective attention and aging. The second goal is to provide an evaluation of inhibition as a theoretical concept in theories of cognitive aging, with a specific focus on attention and aging. Finally, the more general problem of evaluating progress in theory development will also be considered.

In their 1988 chapter, Hasher and Zacks stated that much of their work up until that time had been carried out in the context of a general capacity view of the information processing system. This view holds that cognitive functioning is limited by the amount of resources available on a moment-to-moment basis, and that this capacity declines from early to later adulthood. Their review of more recent work in that chapter is followed by the suggestion that "it may be time to reconsider the heavy reliance on reduced capacity views in cognitive gerontology" (p. 208). They go on to enumerate what they believe to be the conceptual and empirical limitations of the limited capacity approach: the absence of precise specifications about how reduced resources affect cognitive processes, indecision about whether resources are best considered in terms of a single pool or as multiple, independent pools, and the lack of valid and reliable measures of capacity. They then conclude with a new framework for understanding aging and cognition built around the concept of inhibitory function. Each of the criticisms levied against capacity theory will be considered below as they apply to attempts to understand inhibition in attention and aging.

What Is the Role of Inhibition in Selective Attention?

In general, criticisms of capacity theory have focused on the rudimentary nature of the theory. For example, Hasher and Zacks (1988) cite the lack of specification or agreement about what exactly resources are and how resource limitations affect mental functioning. The parallel for inhibitory theory concerns the difficulty in specifying how inhibitory processes affect information processing. For example, in the case of selective attention, one might predict that inhibition prevents distractor information from interfering with target processing, and that good inhibitors should also show reduced susceptibility to interference. These assumptions have been tested in studies using the negative priming paradigm as has much of the empirical and theoretical work on the role of inhibition in attention and aging.

In a typical experiment involving the negative priming paradigm, a series of displays are presented which each require the subject to select and respond to a target stimulus and ignore any distracting stimuli. Negative priming is the lengthening of response time that occurs when a stimulus that was presented as a distractor on one trial (often called the prime trial) is re-presented as a target on the very next...
trial (often called the probe trial). Identity negative priming is indexed by slowing on trials when the name of the target is the same as the name of the distractor on the just-previous trial. Location negative priming is indexed by a slowing of reaction times on trials in which the location of the target is the same as the location of the distractor on the just-previous trial (see Figure 1 for sample stimuli). The theoretical interpretation of this lengthening of reaction times in the negative priming condition is that efficient inhibitory processes acted to exclude distractors from further processing. When the distractor becomes the target on a subsequent trial, inhibition then delays access to the target. The magnitude of the slowing is taken as an index of the strength or efficiency of inhibitory function.

In a test of the assumption that the role of inhibitory processes is to reduce interference from distracting information, Stoltzfus, Hasher, Zacks, Ulivi, and Goldstein (1993) measured both interference and inhibition in a negative priming task involving pairs of red and green letters. The task was to name the target letter of one color and ignore the distractor letter of the other color. Inhibition was assessed in terms of response-slowing in the negative priming condition in which the prime distractor was re-presented as the probe target, relative to the control condition. Interference was assessed in terms of response-slowing in the control condition relative to a condition in which no distractors were present. If inhibition acts to suppress distractor activation when target and distractor are presented simultaneously, then the strength of inhibitory processes brought to bear should be inversely related to the extent of interference experienced. However, Stoltzfus et al. (1993) report no relationship between inhibition and interference among either young or old adults, and conclude that findings such as theirs “provide less than strong support for the supposition that inhibition inevitably functions to reduce interference during concurrent selection” (p. P186).

Connelly and Hasher (1993) also reported finding no significant correlation between measures of interference and suppression, again suggesting that interference and inhibition, or negative priming effects, are not necessarily related. However, Swerdlow, Filion, Geyer, and Braff (1995) reported a small but significant correlation between negative priming measured in a location suppression task, and interference in the Stroop task. Earles et al. (1997) found a small but significant correlation between inhibition and interference in their negative priming data, but no significant correlation between inhibition and any other interference measures, including Stroop interference and interference from irrelevant information present on the page during reading. They concluded that this pattern of results “did not support the hypothesis that the age-related increase in susceptibility to interference is due in part to inhibitory deficiencies” (p. 56). Kieley and Hartley (1997) report correlational data that are ambiguous in the question of the relation between inhibition and interference. They observed a nonsignificant negative correlation, but acknowledged that the low reliability of the inhibition task they used may have artificially reduced the correlation. The issue of measurement reliability is revisited below; for now, the problem of low reliability and the mixed correlational results just de-
scribed provide no clear answer as to how inhibitory decline might affect mental functioning.

One post-hoc account of the role of inhibition, attributed to Stoltzfus et al. (1993) by Connelly and Hasher (1993), is that "inhibition functions not to reduce activation of a concurrent distractor, but to enable the previously selected target to gain momentum toward establishing a coherent stream of thought by slightly retarding the development of excitation to the just-rejected distractor" (Connelly & Hasher, 1993, p. 1248). If this were the case in negative priming tasks, however, then the magnitude of negative priming observed might be expected to be reduced as prime-probe interval is increased. That is, if inhibition acts simply to give prime target information a head start over the distractor in the build-up of activation, then as more time goes by before the probe trial is presented, the distractor should attain more and more activation and be less and less likely to produce response slowing on the probe trial.

However, Hasher, Stoltzfus, Zacks, and Rypma (1991) and Stoltzfus et al. (1993) used prime-probe intervals ranging from 300 to 1700 ms. The data are shown in Figure 2; they observed no alteration in the magnitude of the negative priming effect in young adults. Thus, this suggestion about the role of inhibition is either incorrect, or in need of further elaboration in order to be tested more directly. In summary, the findings reviewed in this section indicate that, similar to capacity theory, the inhibitory deficit framework has not yet produced consensus regarding a definitive role for inhibition in cognitive function.

Another account of the role of inhibition offered by Stoltzfus et al. (1993) is that it acts as "conceptual inhibition of return" (p. P186) that allows the organism to establish and maintain one train of thought and prevent or delay any attention to unwanted or irrelevant thoughts. An evaluation of this suggestion is taken up in the next section in the discussion of the inhibition of return paradigm.

Inhibition — One Mechanism or Many?

A second criticism of capacity theory cited by Hasher and Zacks (1988) concerns the question of whether capacity is best thought of as a unitary construct or as a set of independent pools of resources. The same issue faces theorists employing inhibition in explaining cognitive aging. The findings from studies of negative priming and aging first forced the issue of multiple inhibitory mechanisms when Connelly and Hasher (1993) observed an age deficit in identity suppression but preserved inhibitory function in location suppression tasks. The task in their Experiment 3 required subjects to name a red letter and ignore a green letter (or vice versa), and their trials were ordered to allow examination of age differences in location suppression (Figure 1A-i), identity suppression (Figure 1A-ii), and both in combination (Figure 1A-iii).

The data show that in the location suppression condition, both age groups showed response slowing. Thus, in a letter naming task, both old and young adults show evidence of location suppression, even though location was irrelevant to the task. When a target letter shares the identity but not the location of the distractor letter from the previous trial, young but not older adults showed response slowing, or negative priming. In addition, when both the identity and location of distractor information are repeated as the target stimulus, the effects of identity and location suppression appear additive for young adults, whereas older adults are not any more slowed than they are for location suppression alone. These results indicate a dissociation in the inhibitory function of older adults; age deficits are apparent in identity suppression, whereas age equivalence is observed in location suppression.

Connelly and Hasher (1993) suggested that this pattern of results may be related to neuropsychological work which has identified separate visual pathways — one that processes identity, or "what is it?” information, and another that processes location, or “where is it?” information (e.g., Harter & Aine, 1984; Moran & Desimone, 1985). The behavioral data suggest that the identity pathway is age-sensitive, whereas the location pathway is not. As noted by Connelly and Hasher, however, relatively little evidence is available to confirm or reject this suggestion regarding the aging visual system. In addition, subsequent work indicates that the attempt to characterize age equivalence and age deficits in negative priming in terms of location suppression and identity suppression, respectively, may not hold up.

One finding that calls into question the dichotomy between preserved location suppression and impaired identity suppression in aging is reported by McDowd and Filion (1995). They have shown that age differences in location suppression are observed in a negative priming task when preparatory interval is manipulated; thus, location suppression is not universally preserved in aging. In addition, although several studies have shown age deficits in identity suppression in tasks requiring selection among letters (e.g., Hasher et al., 1991; McDowd & Oseas-Kreger, 1991; Stoltzfus et al., 1993), words (e.g., Kane, Hasher, Stoltzfus, Zacks, & Connelly, 1994), and pictures (e.g., Tipper, 1991), there are now several studies reporting age equivalence in identity negative priming, further muddying the waters with regard to the dichotomy between identity and location suppression mechanisms.

Sullivan and Faust (1993) reported the first study in which age equivalence was observed in an identity negative priming task. Their task required naming one of two superimposed line drawings — one red and one green. A sample stimulus display is shown in Figure 1B. In this study, significant identity negative priming was observed both in
young adults and in two samples of older adults. The investigators even ran a second group of older adults just to be sure they hadn’t made a mistake! Their initial finding of age equivalence was replicated in the second sample. In addition, a subsequent study (Sullivan, Faust, & Balota, 1995) also produced identity negative priming in normal older adults using a similar identity suppression task.

Age equivalence in identity negative priming has also been reported by Kramer, Humphrey, Larish, Logan, and Strayer (1994). They presented subjects with a display containing four letters from the set D, V, M, and L. On each trial a location marker appeared under one of the four letters; the subject’s task was to report that letter. On a given trial, the identity of the target was unique and the distracting letters were all the same. When the ignored letter was then re-presented as the to-be-named target, both old and young showed significant slowing, or negative priming. Further analyses determined that this finding was not simply location suppression masquerading as identity suppression; this led Kramer and colleagues to conclude that inhibitory deficits appear to be specific rather than general, and that multiple inhibitory mechanisms will likely be required to provide an adequate account of age differences in performance.

Finally, two other studies report identity negative priming in older adults. Earles et al. (1997) reported significant identity suppression among older adults in their task requiring word naming based on the task first described in Kane et al. (1994), although they did observe more identity suppression among young adults. Kieley and Hartley (1997) have shown age equivalence in identity suppression in their Stroop color-word version of negative priming. Taken together, these studies indicate that a simple dichotomy between identity suppression and location suppression is insufficient to account for inhibitory function in aging.

**The episodic retrieval hypothesis.** — In an effort to reconcile seemingly disparate findings regarding inhibition and aging in negative priming and to preserve the notion of an age-related inhibitory deficit, other accounts of response slowing in negative priming have been proposed. One such alternative is an episodic retrieval mechanism, which is capable of producing negative priming but does not involve only inhibitory processes (e.g., Neill, Valdes, Terry, & Gorfein, 1992). An episodic retrieval mechanism may come into play in a serial stimulus identification task (which describes most negative priming tasks) if the task includes the use of degraded stimuli and a large number of occasions in which the same target is used in immediately successive displays. In either case, the subject might find it useful to recall previous episodes for help in identifying the current target. If this strategy is adopted, it could produce response slowing on negative priming trials in the following manner: If the subject has adopted a strategy of retrieving the just previous episode, then in the negative priming condition a conflict is introduced between the “do not respond” tag associated with the prime distractor stimulus, and the “respond” tag that is now associated with that stimulus on the probe trial (Fox, 1995, p. 146). Response slowing in these conditions is due to this conflict and the time required to resolve it, not to inhibitory processes.

May, Kane, and Hasher (1995) have suggested that data showing intact identity negative priming in older adults come from tasks in which episodic retrieval produced the response slowing rather than inhibitory function. The tasks used by Sullivan and Faust (1993), Sullivan et al. (1995), and Kramer et al. (1994) do involve characteristics that have been identified as likely to elicit an episodic retrieval strategy (e.g., a large number of trial pairs that involve the same target stimulus). Thus, according to May et al., these studies do not contradict the inhibitory deficit hypothesis because the tasks used do not assess inhibitory function. However, the tasks used by Kieley and Hartley (1997) and Earles et al. (1997) do not involve the conditions for episodic retrieval, yet do show identity negative priming in older adults; these data challenge the inhibitory deficit hypothesis of cognitive aging. These complexities suggest a note of caution about the use of negative priming to assess age differences in inhibitory function. Until we better understand negative priming, it may be premature to use it as any sort of definitive test of the inhibitory deficit hypothesis.

**Inhibition of return.** — Studies assessing inhibition of return have also provided evidence that multiple inhibitory mechanisms will be required to adequately explain attention in aging. Inhibition of return (IOR) is the slowing of target detection when targets appear in a location where attention had been previously directed compared to trials in which targets appear at unattended locations. For example, in a typical task, attention begins at central fixation, is then drawn to a peripheral location by a brightening or flash, then is drawn back to fixation, and finally the to-be-detected target is presented either in an unattended location, or in the previously attended location. The difference in target detection times in the two conditions is called the IOR effect, and the amount of slowing observed in this latter condition is taken as a measure of the strength of inhibition directed at that location.

Hartley and Kieley (1995) reported four experiments examining inhibition of return in young and old adults. Their Experiment 1 assessed inhibition of return in a simple detection task, Experiment 2 involved a 2-choice discrimination task, Experiment 3 involved manipulations to guarantee that attention was actually shifted to cue locations, and Experiment 4 examined the spread of inhibition to locations adjacent to those previously attended. In all experiments, the magnitude of the IOR effect was actually greater for old than young adults. Hartley and Kieley also report data from a task involving both inhibition of return and Stroop components. Using additive factors methodology, this task was designed to address the question of single or multiple inhibitory mechanisms. The task involved the presentation of a colored square to the right or left of fixation, then a colored square at fixation, and then a color word printed in colored letters, presented either in the same location as the first square (the inhibition of return location) or the opposite location. The color word was printed in a congruent color or incongruent color, the latter being the Stroop condition. Subjects had to name the color of the ink in which
the word was printed. Consistent with previous work, Hartley and Kieley observed larger inhibition effects for old compared to young adults in both IOR and the Stroop conditions. However, the interaction of the two factors was subadditive in their sample of older adults, consistent with the hypothesis that the two effects are produced by different mechanisms, or brain systems.

McDowd, Filion, Tipper, and Weaver (1995) assessed both location-based and object-based inhibition of return. They had predicted, based on the location–identity differences observed in some negative priming tasks, that location-based IOR might be intact in older adults, but that object- or identity-based IOR would show an age-related deficit. However, the magnitude of the inhibition of return effect was again greater for older adults than for young adults, for both object-based and location-based inhibition. Thus, no age-related inhibitory decline is in evidence in these IOR data.

Together, these studies make two points. First, they call into question the notion of negative priming as a conceptual inhibition of return, with young adults but not old showing the inhibitory effect, as was suggested by Stoltzfus et al. (1993). Unless that conceptual mechanism is specified and unless it is very different from inhibition of return as described above, it does not fit with the data. Secondly, the data just reviewed regarding inhibition of return underscore again that models of inhibitory function in aging need to include multiple mechanisms of inhibition in order to accommodate the complex pattern of preserved and affected functions. This suggestion parallels that made in the context of generalized slowing models of cognitive aging, where the argument continues as to whether a single slowing factor or multiple domain-specific slowing factors best describe cognitive aging. [That debate is presented in a special section of the March 1994 issue of this journal; see Cerella (1994), Fisk and Fisher (1994), Myerson, Wagstaff, and Hale (1994), and Perfect (1994) for details].

How Is Inhibition To Be Measured?

The third limitation of capacity theory identified by Hasher and Zacks (1988) is the problem of establishing good measures of capacity. They cite “failed attempts to develop broadly applicable measures of available capacity and of the capacity demands of different mental processes” (p. 209). A similar weakness currently limits theory development in the area of inhibition and aging. The problem is in finding independent measures of inhibitory function to confirm the role of inhibition in some other cognitive task of interest. For example, in the context of the visual search literature (e.g., Madden, 1983; Plude & Hoyer, 1985; Rabbitt, 1965; Scialfa, Kline, & Lyman, 1987), Hasher and Zacks (1988; Stoltzfus et al., 1996) suggested that older adults’ slowed target detection in the presence of distractors may be a result of inefficient inhibitory mechanisms. Hartley and Kieley (1995) made a similar suggestion. Indeed, a reasoned analysis of this task might suggest that efficient performance requires that a stimulus array be searched in some systematic manner, with repeated searches of the same areas suppressed by some inhibitory mechanism. The empirical observation that older adults are slower at searching an array than are young adults might be attributed to a failure of this inhibitory mechanism to assure the most efficient search strategy. However, we know from the inhibition of return data just described, that age differences in visual search are likely not due to a failure of that particular inhibitory mechanism. Thus, in this instance, the hypothesized involvement of inhibitory processes is not borne out by available empirical evidence.

Another example illustrating the lack of indisputable measures of inhibitory function is given in the work by Kieley and Hartley (1997). Using Stroop procedures, they tested the notion that situations involving difficult target–distractor discrimination will produce identity suppression in both young and old adults. The Stroop color–word task requires naming the ink color in which target stimuli are presented. In some conditions, the stimuli are color words. When this is the case, and the word and color do not match, a conflict is created between responding based on the ink color, and responding based on the word identity. Accurate performance requires that the word identity be suppressed.

In order to assess identity suppression, Kieley and Hartley compared response times from trials in which the to-be-named ink color on the next trial (negative priming condition) to response times from trials in which no colors were repeated (control condition). The extent to which a color word identity on one trial led to response slowing when the next word was presented in that color was taken as an index of identity suppression, and of the integrity of inhibitory function. Indeed, identity suppression has been nominated as the “best available index of inhibitory attentional processing” (Kane, May, Hasher, Rahhal, & Stoltzfus, 1997, as cited in Kieley & Hartley, 1997). Kieley and Hartley, however, report age equivalence in identity suppression, as had Sullivan and Faust (1993) and Kramer et al. (1994) before them. According to these studies, if identity suppression is the best available index of inhibitory attentional processing, then older adults apparently do not suffer a decline in inhibitory function.

Salthouse and Meinz (1995) also recognized the difficulty “in identifying adequate measures of the inhibition construct” (p. P297). They attempted to test explicitly the relationship between inhibitory processes and working memory in young and old adults, using Stroop interference as the measure of inhibitory function. They report significant overlap in the influence of inhibitory function and processing speed in accounting for age-related variance in working memory, concluding that speed accounts for at least as much of the variance as do “purportedly specific measures of inhibition” (p. P305). A similar finding is reported by Earles et al. (1997), whose study was designed to investigate associations between age, perceptual speed, inhibitory function, susceptibility to interference, and working memory. Their measure of inhibitory function was identity negative priming, obtained with a task involving selection between words of different colors, based on the task reported in Kane et al. (1994). They report reduced negative priming in old relative to young adults, and interpret this finding as evidence of impaired inhibitory functioning in aging. However, they also
report that controlling perceptual speed reduced the age-related variance in inhibition by 84%. Thus, in their view, what appears to be an inhibitory deficit may actually be a consequence of slowing. In addition, Earles et al. (1997) found no relation between inhibitory function and working memory, although they do admit that the small negative priming effects have "little chance" of being statistically significantly associated with the measures of working memory" (p. 56). They conclude that "future research should focus on finding better measures of inhibitory functioning" (p. 56). Indeed, in the absence of a valid, reliable, and pure measure of inhibitory function, it is very difficult to properly assess the hypothesis that inhibitory function declines with age.

More powerful tests of the age-related inhibitory deficit hypothesis will first require specification of inhibitory mechanisms around which tasks can be built to test the notion of an age-related decline in inhibitory function. Such work is made more difficult by the evidence suggesting multiple mechanisms of inhibition. This difficulty is acknowledged by Hasher and Zacks in reference to the parallel task of finding a general measure of working memory capacity to predict individual differences in cognition; they state that such a measure has been "elusive" (1988, p. 209), and researchers have had to settle for more specific mechanisms that share specific features with the processes that they are trying to explain. The evidence reviewed in this section suggests that the same may be true for inhibitory deficit models of age differences in selective attention.

Summary and Future Directions

The preceding survey of findings on inhibition in selective attention and aging included a number of instances in which available data were not consistent with the notion of an age-related decline in inhibitory function and identified the components of inhibitory deficit theory requiring further elaboration and modification. Brief mention is now given to other areas of attentional functioning, such as sustained attention and divided attention, that might be explored to diversify our understanding of inhibition; promising directions for specifying the mechanisms underlying inhibitory function are also outlined.

In the measurement of sustained attention, vigilance tasks typically require individuals to maintain attention to a long series of events with the goal of detecting the occurrence of relatively rare target events. Detection accuracy typically declines over time; this decline is known as the vigilance decrement. The literature is somewhat mixed as to whether older adults show a steeper vigilance decrement over time than do young adults (see Parasuraman, Nestor, & Greenwood, 1989). Part of this inconsistency may be due to differing task variables and performance measures across experiments. In any case, it seems plausible that inhibitory processes might play a role in the vigilance decrement; wandering attention or intruding thoughts might distract the individual from the vigilance task and produce a decline in performance over time. Although to my knowledge this possibility has not been tested directly, work by Giambrata (e.g., 1989) on task-unrelated thoughts suggests that it is not irrelevant thoughts that are producing age differences in the vigilance decrement. This is one area where further empirical work explicitly relating inhibitory function to vigilance performance might contribute to our understanding of age differences in performance.

Another domain of attentional functioning in which little work has been done to incorporate notions of inhibition is in divided attention, or dual task performance. One study that is at least suggestive of the role of inhibition in dual task processing is recent work by Hoyer and Vaidya (1996). They note that efficient dual task performance requires that the two tasks not interfere with one another, and hypothesize that age differences in dual task situations can be attributed to an age deficit in selectivity exacerbating dual-task competition. They designed a set of studies to examine the role of inter-task interference in the dual task; their tasks involved either the same or different input modalities and processing domains. They observed greater age differences in performance when the two tasks required selection between similar input and processing modes, and concluded that an age deficit in selective attention may underlie age differences in the efficiency of dual task performance. Whether or not age differences in inhibition underly this age difference in selectivity remains to be seen. Such work, however, could be instrumental in further refining the inhibitory deficit framework.

Further progress toward true understanding, or explanation, will also require careful specification of mechanisms underlying inhibitory function; this will allow testable predictions about age differences in performance. For example, Houghton and Tipper (1994) have made one attempt at developing a "precise mechanistic account of central selection processes" (p. 65). They outlined two mechanisms by which inhibitory processes might act to improve the efficiency of selection performance. The first is a gain control mechanism. When an information processing system is faced with the task of isolating target information for continued processing in the presence of non-target information, the system may accomplish this by boosting the signal representing the target information and dampening the signal representing the non-target information. Houghton and Tipper contend that the process by which one signal is boosted relative to another is rate-limited; that is, it proceeds at a fixed and limited pace. Given this limit, a gain control mechanism which depends solely on facilitative processes (Figure 3A) is slower at isolating target and distractor information than a mechanism with both facilitative and inhibitory components (Figure 3B). The latter can boost one signal and suppress another, thereby greatly increasing the rate at which selection processes can occur.

In the context of this gain control mechanism, if older adults were to rely only on the facilitative component, they would be slower to accomplish selection, and the distractor information would suffer no ill effects of suppression. Indeed, this is the pattern observed in a number of negative priming studies: Young adults show evidence of identity suppression whereas older adults do not (e.g., Hasher et al., 1991; Kane et al., 1994; McDowd & Oseas-Kreger, 1991; Stoltzfus et al., 1993; Tipper, 1991). In addition, McDowd and Filion's (1995) study involving location suppression assessed both inhibition (negative priming) and facilitation
Amplification Only

Gain Control Mechanisms

Range-Limited System

Figure 3. Relative activation levels of distractors (D) and targets (T) as a function of (A) amplification only, (B) amplification and inhibition in a gain control mechanism, and (C) amplification and inhibition in a range-limited system.
Conclusions and Theoretical Considerations

The task that now remains is to come to some conclusion about where we stand with regard to the inhibitory deficit hypothesis. The data reviewed above have revealed some inconsistency and imprecision that need to be addressed. Stoltzfus, Hasher, and Zacks (1996) have stated that their "model-building approach [employs] the strategy of using new data to influence the model’s development" (p. 77). Indeed, their initial hypotheses about an undifferentiated, global, age-related decline in inhibitory efficiency (Hasher & Zacks, 1988) has been modified to suggest preserved location suppression and declining identity suppression (e.g., Connelly & Hasher, 1993). Even more recent data, such as that reported by Kieley and Hartley (1997) showing age equivalence in identity suppression and McDowd and Filion (1995) showing age differences in location suppression, now need to be accommodated in a theory of inhibitory decline in attention and aging.

The adequacy of the inhibitory deficit hypothesis for contributing to understanding depends in part on the goals we set for the science of cognitive aging. For example, the likelihood that inhibition theory will have to specify multiple mechanisms to handle the complex pattern of results in the literature is not necessarily an inadequacy of the theory. Although the goal of theory is presumably to account for the greatest number of facts with the fewest principles (Underwood, 1957), it may not be realistic to have a single-construct theory at this point in time. That is, it may be premature to expect our theories to account for all of cognitive aging, whether by capacity, speed, inhibitory strength, or some yet-to-be identified construct.

Perhaps dissatisfaction with inhibitory deficit theory comes from psychology’s over-reliance on an empirical epistemology in which theories are valued only to the extent that they are compatible with all available data. However, such an epistemology typically produces only narrow and fragmented facts in a noncumulative knowledge base (Newell, 1973; MacKay, 1993). Although empirical “fecundity is a sign of vitality” (Newell, 1973, p. 286), it may produce “an ever increasing pile of issues, which we weary of or become diverted from, but never really settle” (p. 289) and the integration of knowledge is never achieved. If as empiricists we conclude that inhibition theory is wrong and should be abandoned because there are data to contradict it, we run the risk of losing what benefit was provided by the inhibitory framework as an organizing principle.

A theoretical epistemology, on the other hand, has as its aim the integration of available knowledge. Theories are valued to the extent that they provide an elegant and simple account for a broad range of data, even if there are existing data that run counter to some aspects of the theory. In the interest of integration and a cumulative knowledge base for cognitive psychology, Newell (1973) championed a more theoretical epistemology, suggesting that to discredit a theory because one part of it proved inconsistent with empirical fact was actually theoretically and scientifically irresponsible. MacKay (1993) advocated a theoretical epistemology as a complement to the empirical epistemology that has dominated psychology to date. Under a theoretical epistemology, theories will “not be overthrown lightly” (p. 250); predictions may fail to find empirical support not because the theory is wrong, but because the test was inadequate. The review presented above has illustrated a number of difficulties with producing good tests of inhibitory deficit theory (e.g., identifying pure and reliable measures of inhibitory processes, inadequately specified theory from which to generate predictions), so perhaps it is premature to call for the framework’s rejection. Although we cannot accept theories that are clearly wrong, neither should we disclaim theories when empirical complexities arise. Indeed, understanding does not come from abandoning theory when complexities present themselves, or from failing to acknowledge complexities or counter-evidence when they appear.

The notion of inhibition has long played a role in theories of behavior (see Smith, 1992, for a historical perspective). For example, Ferrier (1876) wrote that “the centers of inhibition constitute the organic basis of all higher intellectual faculties. And in proportion to their development we should expect a corresponding intellectual power” (pp. 17–18). The staying power of inhibition may be a testament to its fundamental importance in behavior; whether it can provide an adequate explanation for some or all of what we observe in cognitive aging remains to be seen.

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