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CHAPTER

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Inhibitory Control, Environmental Support, and Self-Initiated Processing in Aging

The phrase "senior moment" is increasingly common in everyday conversations among people of a certain age. Most such "moments" center on the kinds of errors that adults of all ages make, such as forgetting where you left your keys or parked your car, or the name of a person you've just been introduced to. Nonetheless, older adults believe that such moments are increasingly common (Hertzog, Lineweaver, & McGuire, 1999), and much of the cognitive gerontology literature would agree with this observation (see Balota, Dolan, & Duchek, 2000; Craik & Jennings, 1992; Kausler, 1994; Zacks, Hasher, & Li, 2000). There are, indeed, many circumstances under which the memory performance of older adults is poorer than that of younger adults.

In addition to these senior "memory moments," older adults also are more likely than young adults to complain about what might be called "attention moments," or difficulties in concentrating on intended events. Noise in theaters, restaurants, and at cocktail parties is reportedly more bothersome to older adults than to younger adults. This phenomenon has also been well documented in the laboratory for both visual and auditory distraction (e.g., Connelly, Hasher, & Zacks, 1991; Rabbit, 1965; Tun, O'Kane, & Wingfield, 2001; Tun & Wingfield, 1999; Zacks & Hasher, 1994; see Hartley, 1992, for a review). Indeed, a central focus of theorizing in the cognitive gerontology literature has been to explain the empirical findings that are consistent with these sorts of self-reports.

Recently, three major perspectives have attempted to integrate a broad range of findings of age differences in the cognitive gerontology literature, including both memory and attention moments. Proponents of theories that focus on processing speed deficits (e.g., Cerella, 1985; Myerson, Hale, Wagstaff, Poon, & Smith, 1990; Salthouse, 1991, 1996) argue that slowing of basic-level cognitive processes negatively impacts more complex functions, such as handling distraction, with the result of slowed and inaccurate retrieval. Another class of theories (e.g., N. D. Anderson & Craik, 2000; Craik, 1986; Craik & Byrd, 1982) suggests that older adults' deficits are due to age-related declines in the functional capacity of processing resources, such as working memory. Finally, our own view, stressing inhibitory control, also uses working memory as a central explanatory construct (e.g., Hasher & Zacks, 1988; Hasher, Zacks, & May, 1999). However, rather than focusing on the *capacity* of working memory (or reductions therein), the inhibitory view concentrates on the *contents* of working memory with a particular focus on the relevance of those contents for current goals. Specifically, this view argues that (a) older adults have particular difficulty in controlling what information enters and leaves working memory and (b) inhibitory processes are fundamental in determining both "memory" and "attention" moments, as well as apparent differences in mental capacity and, to some degree at least, in speed as well.

Here we focus on the relationship between the inhibitory viewpoint and ideas central to Craik's viewpoint: self-initiated processing and environmental support. Our conclusion from this evaluation is that there is rather more similarity between these views than a surface consideration might suggest.

☐ The Limited Resource View

The limited resource model of aging posits that older adults are deficient with respect to the amount of mental workspace or energy they have available to perform cognitive tasks. Specifically, Craik and colleagues (e.g., Craik, 1986; Craik, Anderson, Kerr, & Li, 1995; Craik & Byrd, 1982) have suggested that as a result of age-related reductions in this workspace, older adults are less able to engage in the kinds of self-initiated processes that are important for remembering and, as a result, their memory performance is greatly influenced by the amount of support available from the physical environment. In particular, the more support the environment offers, the less the deficit in capacity matters since the environmental cues can drive memory performance.

In this framework, self-initiated processes include retrieval searches and reconstructive activities that individuals execute in the service of a task such as remembering. They may also include processes engaged at encoding, such as the formation of novel connections between and among stimuli, such that several retrieval pathways are created for a particular item. To the degree that these processes are effortful, they require the use of cognitive resources (Craik, 1986; Hasher & Zacks, 1979). Because older adults generally have fewer cognitive resources available to them than do younger adults, older adults have greater difficulty initiating such effortful processes.

However, when environmental support is available for memory, older adults (and others with reduced capacity) can do very well. Some common laboratory tasks, such as cued recall, recognition, and most implicit tasks, provide a great deal of environmental support in the form of cues and context, whereas others, such as free recall and most prospective memory tasks, provide very little. Craik suggested that as environmental support decreases, individuals must increasingly rely on self-initiated processes instead. Not surprisingly, reliable age differences are much more common on tasks in which environmental support is low (and hence the demand for self-initiated processing is high) than on tasks in which environmental support is high (e.g., Craik, 1986; Humphrey & Kramer, 1999; Morrow, Leirer, Andrassy, Hier, & Menard, 1998; Sharps & Antonelli, 1996; Stine-Morrow, Miller, & Nevin, 1999).

☐ The Inhibitory Deficit View

The inhibitory deficit view (Hasher & Zacks, 1988) suggests that a major cause of the cognitive declines associated with aging, including those in memory and comprehension, is inhibitory in nature. Specifically, Hasher and Zacks (1988) argued that compared to younger adults, older adults have spared excitatory attentional mechanisms but less efficient inhibitory mechanisms.

At the core of this view is the argument that attention requires inhibitory constraints over automatically engaged, broad-spread, preattentive activation in order for working memory to function optimally (Cowan, 1995). Efficient inhibition constrains the contents of working memory to information relevant to the immediate goals and demands of a task. In a recent update of the theory, Hasher, Zacks, and May (1999) described three general inhibitory functions that operate at different times in the flow of an information processing sequence, allowing individuals to achieve control over working memory's contents. One function of inhibition operates when information is first presented (or when ideas are activated), preventing the initial access of irrelevant and marginally relevant information into working memory. Evidence suggests that older adults are indeed deficient with respect to this *access function*; this evidence includes a substantial literature on selective attention (see Hartley, 1992,and McDowd & Shaw, 2000, for a review of aging and selective attention; see also Carlson, Hasher, Connelly, & Zacks, 1995; May, 1999).

A second function of inhibition, the *deletion function*, operates when information active in working memory is either irrelevant or only marginally relevant or when information in working memory becomes irrelevant, as occurs when the task or topic changes or when the person's goals change. Bjork (1989) has argued that the ability to discard old information is a crucial step in the process of updating memory representations; by ridding ourselves of nonrelevant information from the current focus in working memory, we make room for more relevant information to enter. A number of studies, including those employing working memory span measures (e.g., Lustig, Hasher, & May, 2001; May, Hasher, & Kane, 1999), garden path sentence and prose materials (Hamm & Hasher, 1992; Hartman & Hasher, 1991; May & Hasher, 1998; Zacks, Hasher, Doren, Hamm, & Attig, 1987), and the directed forgetting paradigm (Beerten, Van Der Linden, & Lagae, 1995; Zacks, Radvansky, & Hasher, 1996; Zacks & Hasher, 1994), have demonstrated age-related deficits in the ability to discard no-longer-relevant information from working memory.

The access and deletion functions of inhibition are relevant to the classic memory finding that the more facts or items attached to a single cue, the slower and more inaccurate retrieval will be (J. R. Anderson, 1974; Watkins & Watkins, 1975). More specifically, a person with inefficient access and deletion functions is likely to have a substantially larger number of facts hooked to each cue compared to a person with efficient access and deletion functions, at least in part because working memory was far more likely to contain information that was nonrelevant along with information that was relevant to the task or goal. As these arguments suggest, the inhibitory framework is able to account for the substantial memory deficits that older adults often demonstrate in laboratory tasks, particularly when environmental support is limited.

The final function of inhibition, the *restraint function*, operates when strong responses are triggered by a familiar cue (e.g., Butler, Zacks, & Henderson, 1999; May & Hasher, 1998). The ability to restrain such responses is especially important whenever the most potent response is not the most appropriate and when alternative responses need to be considered. However, because it is not entirely germane to the current focus, the restraint function is not discussed further.

Deficient Access Control: An Example of Environmental Nonsupport

The access function of inhibition has important implications not only for online performance but also for retrieval. When efficient, the access function permits only task-relevant information (whether that information originates in the environment or in thought) to enter into the focus of attention or working memory. If the access function is not efficient, as is the case for older adults, then irrelevant information enters working memory and, for example, can slow the processing of relevant information. As a result, irrelevant information in working memory will be bound to or associated with relevant information in working memory. When a retrieval cue is presented sometime later, the irrelevant information competes with the task-relevant information, impeding its retrieval.

On this view, then, older adults can be thought of as functioning under more or less continuous divided attention circumstances. Indeed, dividing young adults' attention at encoding—in essence, disrupting their ability to control access to working memory by forcing them to attend to irrelevant information—disrupts their later retrieval of the relevant information, simulating the performance of older adults under normal encoding circumstances (e.g., N. D. Anderson, Craik, & Naveh-Benjamin, 1998; Naveh-Benjamin, chapter 15 of this volume).

Can environmental support help reduce these inhibitory-based age differences in distraction? Recent work by Rahhal, Hasher, and Colcombe (in press) suggests that a small change in instructions given to older adults might be helpful in at least some memory situations. Older adults are typically quite concerned about their memory performance, and thus under the standard ("memory"-intensive) instructions used in laboratory studies, intrusive thoughts and worries are quite likely to serve as highly salient but irrelevant information that distracts them from the memory task. Thus, when older adults are told that they will be required to remember something, their attention may well be divided between the memory task and their concerns about performing well. Rahhal et al. found that reducing the usual emphasis on words related to memory in the instructions (e.g., "remember," "retrieve," etc.) boosted the memory performance of older adults substantially, with little impact on the performance of younger adults. It is possible that reducing the emphasis on memory in the instructions reduced the degree to which older adults were distracted by these irrelevant thoughts during encoding and retrieval, resulting in higher levels of recall than when more standard instructions are used. Thus, task instructions can vary in their degree of environmental support. Indeed, it may not just be task instructions that influence this type of environmental support, it can be the name on the door of a laboratory in which people are tested or the wording of informed consent forms or of telephone calls and letters used to recruit and schedule older adults.

We turn now to another consequence of deficient inhibitory control over access: slowing. One potential inhibitory-based source of the slowing typically shown by older adults is tied to the availability of too much information in the environment. An example of the disruptive effect of too much information is seen in a reading-with-distraction task (Connelly et al., 1991; see also Carlson, Hasher, Zacks, & Connelly, 1995; Li, Hasher, Jonas, Rahhal, & May, 1998) in which younger and older adults read passages embedded with one of four types of visual distraction: blank spaces, strings of Xs, words unrelated to the theme of the passage, and words related to the passage. Older adults are more bothered by distraction (as indicated by slower reading times) than are younger adults, although this is especially true to the extent that the distractors match the target material on a dimension (here, meaning) relevant for the goals of the task.

Other contexts in which distraction may differentially affect apparent processing include measures of cognitive speed that are widely used in the group and individual differences literatures. In most such tasks, many highly similar stimuli are presented at once on a single sheet of paper or in a single computer display, with participants instructed to solve as many problems as possible in a limited amount of time (see e.g., Salthouse, 1996). Thus, the standard speed tasks implicitly require participants to ignore many other currently irrelevant items while solving the single item that is currently relevant. If older adults are less able than young adults to ignore distracting information on a page in order to focus only on the current stimulus (and the selective attention literature would suggest this is so), this will interfere with their ability to complete each item on the test, and this interference may well be seen as a slowdown in responding. The multistimulus displays of standard speed tasks (and "busy" displays in many laboratory or real-life situations) may then constitute a form of environmental "nonsupport."

To test this possibility, we varied the distraction present in the displays of a variety of traditional speed tasks (Lustig, Tonev, & Hasher, 2000; Tonev, Lustig, & Hasher, 2000). Such tasks typically require participants to make simple, rapid decisions about a series of stimuli. For example, in the Letter Comparison Test (see Salthouse, 1993), individuals are instructed to decide whether two strings of letters are identical. On the standard version of the test, many pairs of letter strings are presented in columns on the page; participants work their way down the columns deciding whether the two members of each pair are the same or different.

We compared the performance of younger and older adults across two different versions of the Letter Comparison task. The first, "high-distraction" version simulated the standard, paper-and-pencil test: Pairs of letter strings of varying lengths were presented in columns on the screen. In the second, "low-distraction" version, each pair was presented individually. The logic was simple: If age differences on tests of "cognitive speed" are influenced by age differences in inhibitory control over access to working memory, then age differences in performance should be reduced in the low-distraction version relative to the high-distraction version. This was indeed the case (see Figure 23.1). The presence versus absence of distraction had little or no effect on the performance of younger adults. By contrast, older adults were reliably slower on the standard, high-distraction version than on the low-distraction version. These findings suggest that age-related reductions in the efficiency of the access function of inhibition may contribute to age-related slowing on many tests designed to measure cognitive speed.

In the above examples, extraneous, distracting information from the environment impaired the performance of older adults. It is worth noting, however, that distracting information can either *help or hurt* the performance of older adults, depending on the nature of the distraction in conjunction with the nature of the test task. When environmental information is congruent with the requirements of the task, older adults' greater tendency to take in additional information (due to poor inhibitory control over access) may improve rather than harm their performance. For instance, May (1999) found that if nominally irrelevant, to-be-ignored words were presented on the same computer screen with word problems, the success of older adults on the task depended on the relationship between the distraction and the solution to the problem. When the distracting information led towards solutions (to word problems presented on the Remote Associates Test; Mednick, 1962), older adults benefited to a greater degree than did younger adults. Conversely, older adults were more negatively affected than younger adults when the distracting information led away from solutions.

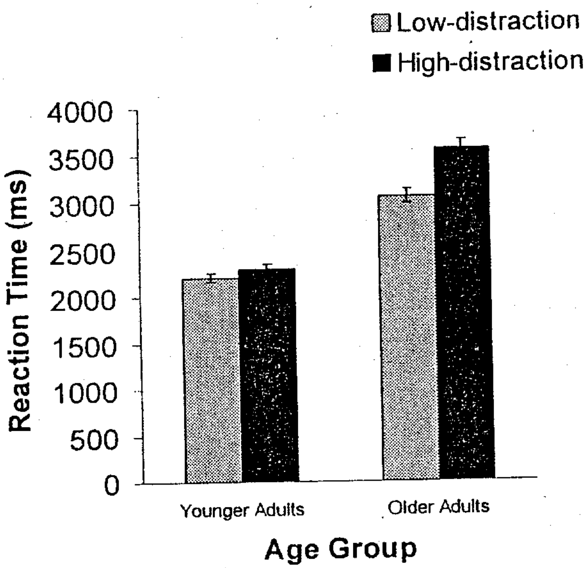

FIGURE 23.1. Younger and older adults' mean correct reaction time on a letter comparison task as a function of distraction.

The access function of inhibitory control constrains how much nonrelevant information enters working memory. The nonrelevant information can actually occur in the external environment or can be triggered by objects and events in the external environment and can even be irrelevant thoughts in response to relevant information. In any event, task-irrelevant information can disrupt performance in a variety of ways. It can reduce subsequent recall by permitting thoughts about performance levels to enter working memory (Rahhal et al., 2000) or by permitting off-track thoughts in response to target information.[1] It can slow performance on a variety of speed tasks whether they are unfamiliar (as in the Letter Comparison task) or quite familiar (as in reading with distraction; e.g., Connelly et al., 1991). It can also alter verbal problem-solving success (as in May, 1999). Thus the external environment can be helpful for performance, as Craik and his collaborators have often shown, but if the information in the environment is irrelevant or only marginally relevant to the current task and goals, it can also disrupt performance. This is particularly so for older adults who are less efficient than younger adults at preventing extraneous contextual information from entering into the focus of attention or working memory (e.g., Hasher et al., 1999; May, 1999).

[1]Because of the connection being made here with Craik's notion of environmental support, we have emphasized the importance of the access function in controlling activation of extraneous events in the environment. It is possible that both the environmental support/interference ideas and the inhibitory ideas can explain these effects equally well. In addition, however, the access function also controls irrelevant thoughts in response to ongoing relevant processing. Thus, an experimental sentence about a doctor who slices an apple pie into six pieces is more likely to trigger irrelevant thoughts (when's my doctor's appointment? My doctor's too thin; she can't possibly eat pie) in older than in younger adults. It is not clear that the environmental support notion handles such phenomena with as much ease as does the inhibitory control notion.

Deficient Deletion: An Example of Poor Self-Initiated Processing

The *deletion function* of inhibition serves to remove marginally relevant, irrelevant, and no longer relevant information from working memory. No longer relevant information is suppressed whenever there is a switch in tasks, topics, or goals. A number of findings indicate that older adults are impaired at this function relative to younger adults.

For instance, using garden path sentences, Hartman and Hasher (1991; see also May, Zacks, Hasher, & Multhaup, 1999) found that older adults were less able than younger adults to forget the recent past when explicitly instructed to do so. As the name suggests, experiments involving "garden path" materials involve misleading individuals to entertain a conceptual representation that is then subsequently disconfirmed. The disconfirmation requires adopting a different conceptual representation. Hartman and Hasher (1991) presented participants with sentence frames such as, "Before you go to bed, be sure to turn off the ________," and instructed them to generate the missing final word. As anticipated on the basis of norms, most participants predicted the likely ending, "lights." Participants were asked to remember the completion word that was then actually provided by the experimenter. For critical sentences, the ending was always a plausible, but less probable ending (e.g., "stove") than the one most participants generated.

Retention of the critical, final words (both the ones that were generated and the ones that were provided by the experimenters) was determined by an implicit memory task. In this task, participants were given medium cloze sentence frames and were asked to complete the missing, final word for purposes connected to what they thought was an entirely different study. The particular sentence frames were normed to have baseline completion rates with the critical words of approximately 50% among naive control subjects. There was a long series of such sentences, and participants were asked to provide a final word, using in each instance the first word that came to mind. Embedded among sentences, with no connection to items in the first part of the experiment were experimental sentences that were used to test for access to the subject-generated ("lights") or experimenter-provided ("stove") critical items from the first part of the study. Using data from participants who showed no awareness of any connection between the two critical parts of the study, Hartman and Hasher (1991) found that younger adults showed greater priming for target endings than for disconfirmed endings, indicating that they were successfully able to discard their original representation. In contrast, older adults showed equal priming for both target and disconfirmed endings (see also May & Hasher, 1998; May, Zacks, et al., 1999).

Thus, older adults carry along the recent past with them, as indicated by greater priming for no-longer-relevant information relative to younger adults, who may show little or no priming for such information. Within the context of the present discussion, such failures can arise as a result of poor self-initiated processing of the sort that would ordinarily serve to delete no-longer-relevant information from working memory. The failure to successfully delete such information has a number of consequences. Perhaps the most profound among these is the heightened interference at retrieval from still partially active, but not currently relevant, information which became part of the memory representation that now includes both relevant, and no-longer-relevant information. This pattern—an increase in the number of elements in a single memory bundle—is sometimes called a "fan," and fan size is known to be inversely related to recall speed and success (J. R. Anderson, 1974). In accordance with the inhibitory deficit perspective, a number of studies have indicated that older adults are more vulnerable to fan effects than are younger adults (Gerard, Zacks, Hasher, & Radvansky, 1991). In addition, these fan effects are widely seen as the basis for proactive interference, a major source of retrieval failures (Zechmeister & Nyberg, 1982). It is not surprising, then, that older adults are more vulnerable to proactive interference effects than younger adults (for reviews, see Kane & Hasher, 1995; Lustig & Hasher, 2001).

Older adults' vulnerability to proactive interference can have a wide range of consequences, including difficulties on tasks traditionally used to assess working memory capacity, namely, working memory span. On a typical working memory span task (e.g., Daneman & Carpenter, 1980), participants are exposed to multiple trials in which they are required to both process (e.g., comprehend a series of sentences) and store information (e.g., the last word of each sentence) for a recall test that follows each of a series of sentences. This multiple trial methodology carries with it the possibility that information from earlier trials may proactively interfere with recall of information from later trials (May, Hasher, & Kane, 1999a). Specifically, May, Hasher, and Kane suggested that while individuals are attempting to complete later trials, information from earlier trials might still be active, disrupting retrieval of the current trial's information. It follows that individuals will perform efficiently on this task to the extent that they can delete prior trials from working memory.

To test their claim, May, Hasher, and Kane (1999) attempted to reduce the effect of proactive interference on memory span via an alteration in the way in which lists were presented: Span tests typically begin with the participant having to remember few items, with the memory load (or list length) gradually increasing as test trials proceed. This creates the potential for items from the briefer, earlier trials to proactively interfere with those on the longer, later trials that are critical for getting a high span score. Thus, May, Hasher, and Kane simply reversed the presentation such that testing began with longer list-length trials and then gradually proceeded to briefer trials. In this way, longer trials were administered before proactive interference was built up, and the shorter list-length trials (e.g., those with two items) were simple enough that they were not adversely affected by proactive interference.

For participants tested using the standard administration (long trials last), the standard age differences were obtained: Older adults had reliably smaller working memory span scores than did young adults (see, e.g., Gick, Craik, & Morris, 1988; Salthouse & Babcock, 1991). However, older adults' performance was much improved when the span task was administered using the alternative, interference-reducing method (see Figure 23.2). Indeed, the performance of older adults tested in the interference-reducing method was not statistically different from that of young adults (see also Lustig et al., 2001).

These results clearly show that the age deficits in working memory span often obtained in the commonly used reading span task (see, e.g., Daneman & Merikle, 1996) are at least partially the result of older adults' reduced ability to delete now-irrelevant information from previous trials from working memory. This poses a particular problem for capacity-based explanations of age declines in cognitive performance, at least to the extent that these explanations rely on working memory span as an estimate of capacity: When the inhibitory (deletion) demands of the span task were reduced, older adults showed equivalent capacities (span scores) as young adults. Together with other findings of older adults' reduced deletion efficiency (e.g., Hartman & Hasher, 1991; May, Zacks, et al., 1999, these results strongly suggest that age differences in many tasks, including working memory span, are not due to reduced capacity but are instead the result of age differences in initiating the deletion process that removes irrelevant information from working memory.

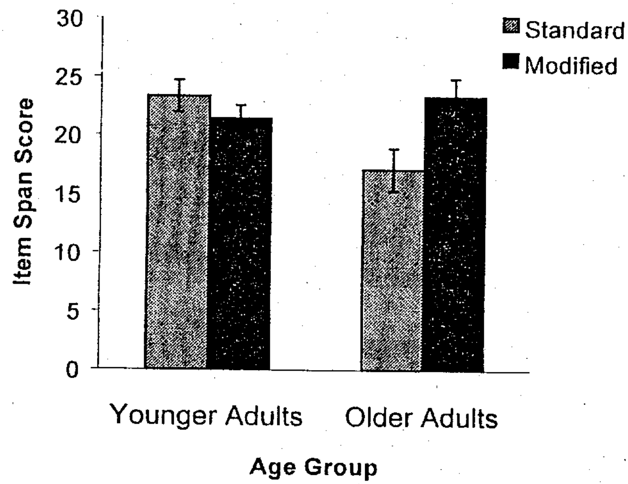

FIGURE 23.2. Younger and older adults' mean item span score on reading span task as a function of format: Standard (ascending) versus Modified (descending). (Adapted from May, Hasher, & Kane, 1999.)

☐ Conclusions

From a theoretical standpoint, the findings presented here are consistent with the idea that inhibitory control over attention is an important cognitive function that probably differs among individuals but that certainly differs with age, manifesting itself as slowing in some instances and as reduced working memory span in others.

We note especially that in some ways, these ideas map rather nicely onto Craik's views (e.g., Craik, 1986; Craik et al., 1995) of aging and of age differences in cognition. Older adults may be slower on most speed tasks because the environment not only doesn't support the particular task, but in fact actively disrupts performance even more for older adults than for younger adults (Carlson et al., 1995; Connelly et al., 1991; Lustig et al., 2000; Tonev et al., 2000). Such findings are quite in agreement with the age-related increase in sensitivity to environmental cues that Craik has noted (e.g., Craik, 1986). We would attribute these age differences to declines in inhibitory control over access to focal attention or working memory, declines that result in the physical and mental environments (e.g., Rahhal et al., in press) playing bigger roles in the performance of older than of younger adults.

In addition, when tasks shift their focus, for example from list 1 to 2, or passages shift their topics, older adults are much less able to stop the processing of the earlier task than are younger adults. This reduced ability (as the inhibitory framework would suggest) to suppress the no-longer-relevant past may be an instance of older adults' reduced ability to engage in self-initiated processing.[2] In the present instance, a major consequence is a

[2]We note this parallel with some reservation because the Craik notion of self-initiated processing may in general have a rather more deliberate, effortful, strategic quality to it than does the Hasher et al. notion of inhibition.

decrease in the ability to recall in a wide range of tasks, including even working memory span tasks (e.g., Lustig et al., 2001; May, Hasher, & Kane, 1999a).

Thus, as we see it, Craik's ideas and the inhibitory framework of Hasher and Zacks have some key ideas in common. The views differ in their ultimate explanation (or possibly in their level of explanation), of course, with Craik and his collaborators relying on the notion of capacity and reductions in capacity that presumed to be associated with aging, and with the inhibitory framework relying on what we take to be the underlying determinant of the apparent age-related (or even individual) capacity differences, inhibitory-based attentional processes.

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