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Inhibitory control over the present and the past

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From the perspective of the Hasher, Zacks, and May (1999) inhibitory framework, optimal performance occurs only when there is control over nonrelevant information. Relative to a current, goal-directed task, there are at least two potential sources of nonrelevant information that need to be controlled. The first is no longer relevant information. Such information would include, for example, a previous topic of conversation, or, in our work, a previous list of materials presented for study and recall. The second source of nonrelevant information is currently present (in thought or in the world) stimuli that are not relevant to the task at hand. Inhibitory processes are critical to the effective control of both sources of information—the no longer relevant past and the irrelevant present. If inhibitory processes are inefficient, irrelevant information from both the past and the present will disrupt performance on the current task. We illustrate this with studies showing the role of irrelevant information in reducing the working memory capacity of older adults and in slowing them down as they do even reasonably simple tasks.

"*Oops! My mind wandered for a second—could you repeat that, please*?"

We've all had occasion to say something like this during a conversation, even one that we were interested in and motivated to attend to. Perhaps

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the mention of a mutual friend's name sparked a memory for the entertaining dinner you had with her last weekend, and you spent a moment too long reminiscing; perhaps an interesting person across the street caught your eye and distracted you from the conversation. These examples show how extraneous information—either from the environment or one's own mind—can divert one's attention from the task at hand.

Our theoretical framework (Hasher et al., 1999) emphasises the importance of inhibiting this extraneous information for controlling goal-directed behaviour. By this framework, keeping attention focused on the information important for current activities via the suppression of irrelevant information plays a critical role in the successful performance of many tasks, both current and future (e.g., remembering). We further suggest that many of the difficulties older adults face on laboratory tests and in everyday life stem from an age-related reduction in inhibitory control. Other views of cognitive ageing emphasise age changes in the capacity or speed of information processing (e.g., Craik, 1986; Salthouse, 1996), our view focuses the importance of *efficient* processing, such that attention is occupied only by information relevant to accomplishing current goals. Failures to keep attention free from irrelevant information can disrupt both present performance and memory.[1]

In this paper, we concentrate on how the failure to inhibit memories that have become irrelevant can hamper the retrieval of currently important memories, and how distraction from irrelevant information in the environment can impair performance even on simple and well-practised tasks.[2] To this end, we describe studies using both young adults, who are relatively good at inhibiting irrelevant information (at least at their optimal time of day; see Yoon, May, & Hasher, 2000), and older adults, who often have difficulty inhibiting irrelevant information and thus are very vulnerable to its effects.

IRRELEVANT INFORMATION FROM THE PAST: ITS IMPACT ON RETRIEVAL

In an earlier example, memories for a previous outing with a friend served as distraction from a current conversation. Irrelevant information

[1] Although we will not further explore this issue here, neuroimaging and neuropsychological evidence suggests that age-related declines in attentional control may be related to age-related changes in the frontal lobes of the brain (see Moscovitch & Winocur, 1995; Shimamura & Jurica, 1994; West, 2000).

[2] These concerns relate to the *deletion* and *access* functions of inhibitory control, respectively. The full framework (see Hasher et al., 1999) includes a third function for inhibition, the *restraint* of dominant but currently inappropriate behaviours.

from the past can also hamper the ability to correctly remember new information. For example, suppose that this friend has recently moved, leading to a change in address and phone number. When calling your friend to arrange another outing, you may find it difficult at first to remember her new phone number because the memory for the old number "gets in the way of", or interferes with, its retrieval.

Laboratory studies of the detrimental effects of previous information often use paired-associate list procedures in a proactive interference design. In the paired-associate procedure, the participant is presented with, say, 10 pairs of items to be learned and recalled on a later memory test. One item in each pair is designated the "stimulus" or "cue". The other item is the "response". The participant's task is to learn to give the correct response to each stimulus item. In a proactive interference design, participants next learn a second list of paired-associates, in which each stimulus word from the first list is paired with a new response word (e.g., List 1: SHIRT–WINDOW; List 2: SHIRT–FINGER). After learning the second list, participants are then given the stimulus words as cues, and their memory for the second-list response terms is compared to that of a control group, who either learned only the second, critical list or whose first list used different stimulus items (e.g., List 1: ENERGY–WINDOW; List 2: SHIRT–FINGER). Participants in the proactive interference condition reliably show worse memory for the second-list responses than do control participants (for reviews see Anderson & Neely, 1996; Crowder, 1976; Keppel, 1968; Postman & Underwood, 1973; Underwood, 1945).

For participants in the proactive interference condition, inhibition of irrelevant information from the past (i.e., the first list) may be important both for learning the second, critical list and for producing the second-list response terms on the memory test. Learning the second-list response terms will be easier if the first-list responses are suppressed, so that they do not compete with the second-list response terms and disrupt their learning. Likewise, for the memory test, participants in the proactive interference condition must limit the retrieval of the now-irrelevant first-list items in order to successfully remember the critical, second-list items. Thus, the successful learning and remembering of the critical second-list items depends on the inhibition of the now-irrelevant items from the first list. Older adults are less likely to inhibit these irrelevant items from the past and thus are more likely to retrieve them (e.g., Hamm & Hasher, 1992; Hartman & Dusek, 1994; Hartman & Hasher, 1991; May & Hasher, 1998; May, Zacks, Hasher, & Multhaup, 1999), and older adults often show larger proactive interference effects than do young adults (Kane & Hasher, 1995; Lustig & Hasher, in press; Winocur & Moscovitch, 1983).

Irrelevant information from the past can also hurt performance on tasks with much shorter lists than are commonly used in paired-associate tasks (e.g., Keppel & Underwood, 1962). An important modern example is the impact of interference on the span tasks commonly used to measure working memory capacity, or the amount of information that can be simultaneously processed and stored (e.g., Baddeley, 1986; Baddeley & Hitch, 1974; Daneman & Carpenter, 1980, 1983; Just & Carpenter, 1980, 1992). Working memory capacity is thought to be an important determinant of performance on many tasks, especially language and reading comprehension (see Daneman & Merikle, 1996 for a review). Consistent with this idea, working memory span performance predicts performance on numerous tasks, including reading, problem solving, writing, and prose recall (e.g., Daneman & Carpenter, 1980; Dempster & Corkill, 1999; Gernsbacher, 1997; Kyllonen & Christal, 1990; Logie, Gilhooly, & Wynn, 1994; MacDonald, Just, & Carpenter, 1992; Stine & Wingfield, 1990). Young children, older adults, poor readers, and various patient groups typically obtain lower working memory span scores than do healthy college students (e.g., Brebion, Amador, Smith, & Gorman, 1998; Frisk & Milner, 1990; Gabrieli, Singh, Stebbins, & Goetz, 1996; Gernsbacher, 1997; Gick, Craik, & Morris, 1988; Light & Anderson, 1985; Salthouse & Babcock, 1991; Siegel, 1994; Swanson, 1993). Presumed group and individual differences in capacity, as measured by working memory span tasks, are thought to lead to differences in many areas of cognitive performance.

However, a close examination of many working memory span tasks reveals that their design actually encourages the build-up of proactive interference. For example, in the most commonly used span task, the reading span task (Daneman & Carpenter, 1980), each trial consists of a short series of sentences, at the end of which participants are asked to recall the final word of each sentence in the series. After completing five series of two sentences, participants are given five series of three sentences, then four sentences, and so on until they can no longer reliably produce the final words for all the sentences in the series. The largest series at which a person can reliably produce all the sentence-final words is used as the measure of his or her working memory capacity. Although working memory span tasks are used as measures of capacity, their structure strongly encourages the build-up of proactive interference. Many words are learned and recalled as the person proceeds through the span task. As a result, now-irrelevant words from previous series may interfere with the retrieval of words from a current series. This proactive interference will have an especially large impact on the ability to remember words from the longer, later series that are important for obtaining a high span score.

Based on this observation, as well as on evidence that individuals and groups thought to be very vulnerable to interference typically have low span scores (e.g., Butters, Delis, & Lucas, 1995; Chiappe, Hasher, & Siegel, 2000; Dempster, 1991, 1992; Gernsbacher, 1997), May, Hasher, and Kane (1999a) tested the effects of interference-reducing manipulations on the span performance of younger and older adults. The first of these manipulations simply reversed the order in which the series of sentences was presented. In this reversed administration, the largest series appeared first, rather than last. Because the large series appeared early in the task, before numerous other words had been learned and recalled, the impact of proactive interference on these trials was greatly reduced relative to the usual version of the task, in which the large series occur last, not first.[3]

When tested using this interference-reducing, reversed administration, the span scores of older adults were much higher than in the standard, interference-heavy administration. In fact, older adults tested in the interference-reducing condition performed as well as young adults, in stark contrast to the usual finding of age-related reductions in working memory span (e.g., Gick et al., 1988; Salthouse & Babcock, 1991; Zacks & Hasher, 1988). The addition of a second interference-reducing manipulation, breaks between each series that increased their distinctiveness, also raised the span scores of young adults (May et al., 1999a). These results strongly suggest that proactive interference impacts working memory span scores, that young adults are less sensitive to proactive interference than are older adults, and that age differences in working memory span may be the result of older adults' greater vulnerability to proactive interference from now-irrelevant past information, rather than age-related reductions in the capacity to store and process information overall.

Working memory span tasks are so commonly used because they are highly predictive of performance on tasks that are thought to be determined primarily by capacity to store and process information, such as reading and language comprehension (see Daneman & Merikle, 1996 for review). The ability to simultaneously store and process information may be especially important in such tasks, since comprehension typically involves integrating the information from a current sentence or phrase with the relevant previous information that will facilitate its interpretation (see Daneman & Carpenter, 1980; Daneman & Merikle, 1996). However, if *irrelevant* information is not deleted from working memory, it may

[3]Of course, proactive interference also builds up as participants progress through the trials in the descending condition. However, it will not have as great an impact on span scores as in the standard condition, since in the descending condition proactive interference will be greatest on the smallest, easiest trials that are least important for obtaining a high span score (rather than the largest, hardest trials that are most important for obtaining a high span score, as in the standard condition).

impair this integration of the *relevant* past and current information, leading to reduced speed and increased errors (see Hasher & Zacks, 1988; Hasher et al., 1999). Thus, a critical question is the degree to which the interference present in working memory span tasks contributes to their ability to predict performance on other cognitive tasks.

To address this question, we asked younger and older adults to read and recall a short story after completing the span task in either the standard or interference-reducing conditions (Lustig, Hasher, & May, in press). The results of this study replicated those of May et al. (1999a): Reducing the influence of proactive interference on the span task raised span scores, and older adults performed as well as young adults in the interference-reducing reversed condition. More importantly, for each age group, the same interference-reducing manipulations that increased span scores eliminated the span task's ability to predict story recall performance (see Table 1). These results fit well with other findings suggesting that individual and group differences on many language tasks are greatly influenced by differences in vulnerability to interference (e.g., Gernsbacher, 1997; Gernsbacher & Faust, 1991; Light & Capps, 1986; Zacks & Hasher, 1988; see Dempster & Corkill, 1999 and Kemper, 1992 for reviews). In combination, these findings strongly suggest that not only are the span tasks that are supposed to measure capacity heavily influenced by interference, but span tasks' ability to predict performance on other cognitive tasks depends upon a shared influence of interference.

Thus, there are (at least) two interpretations of the widespread individual and group differences in working memory span and the ability of working memory span to predict performance on other cognitive tasks.

TABLE 1

Means and standard deviations (in parentheses) of span scores, prose recall scores, and correlation between span and prose recall for older and younger adults (from Lustig et al., in press. Used with the permission of the American Psychological Association)

	Older adults		*Younger adults*		
	Ascending	*Descending*	*Ascending*	*Descending*	*Descending-breaks*
Span score	20.10 (8.07)	23.56 (6.05)	26.20 (8.86)	25.52 (7.21)	30.72 (7.61)
Prose recall	12.43 (3.26)	12.88 (3.56)	14.69 (4.32)	14.72 (3.65)	14.93 (3.94)
Correlation	.29	.08	.27	.33	.02

By the dominant view, working memory span tasks measure the capacity to simultaneously store and process information (e.g., Baddeley, 1986; Baddeley & Hitch, 1974; Daneman & Carpenter, 1980, 1983; Just & Carpenter, 1980, 1992). This capacity is further thought to be a stable trait (though decreasing with age) of fundamental importance in many areas of cognition, especially reading and language and comprehension (e.g., Daneman & Merikle, 1996; Engle, Kane, & Tuholski, 1999). An alternative view calls attention to the heavy influence of interference on both working memory span tasks and the measures they predict, as well as noting that the same people that typically obtain low span scores have been shown in other contexts to be very sensitive to interference (Chiappe et al., 2000; Hasher et al., 1999; Lustig et al., in press; May et al., 1999a; see also Dempster & Corkill, 1999; Gernsbacher, 1997). By this alternative view, individual and group differences (particularly age differences) in working memory span reflect individual and group differences in interference vulnerability, and the ability of span performance to predict performance on other tasks rests on a shared influence of interference. In turn, the present view suggests that what underlies interference effects is the ability (or lack thereof) to suppress no-longer-relevant or never-relevant information. To the degree that people are able to do so, their spans will be large and their performance on any other test containing a memory component, including reading comprehension, will be improved.

In summary, information learned in the past that is no longer relevant can impair performance on a current task. This is true for both laboratory measures of memory, such as the paired-associates and working memory span tests, and for more "real-world" activities such as reading and language. Older adults' greater vulnerability to the detrimental effects of now-irrelevant past information plays an important role in producing age differences on these measures. In some cases, reducing the opportunity for interference from past information can eliminate age differences, such that older adults perform as well as young adults (e.g., Lustig, et al., in press; May et al., 1999a). Age differences in the ability to resist interference from previously learned information, as well as individual differences within an age group, may be responsible for differences on many cognitive tasks that have been previously ascribed to other cognitive constructs such as capacity.

IRRELEVANT INFORMATION FROM THE ENVIRONMENT: THE IMPACT OF DISTRACTION

Extraneous information can also come from the surrounding environment, slowing performance and leading to mistakes. For example, we usually slow down when driving through road construction full of various distractions such as warning cones, machinery, and highway workers. We may attempt to reduce distraction from other sources in order to compensate, turning down the radio and quieting rowdy children in the back seat. Environmental distraction even affects performance on relatively simple, well-practised tasks, such as reading. This consideration has taken on new importance because of increased Internet usage, with web page designers exhorted to avoid crowded text, blinking ads, and other forms of clutter that make extracting the desired information a slow and painful process.[4]

Older adults are less able to ignore environmental distractors than are young adults, as demonstrated by age differences on simple visual attention tasks as well as more complex tasks such as reading and problem-solving in the face of distraction. For example, the presence of distractors in a visual display disrupts older adults' ability to find a target item more than it disrupts young adults' ability (e.g., Cremer & Zeef, 1987; Lepage, Stuss, & Richer, 1999; Rabbitt, 1965; but see Kotary & Hoyer, 1995). As the number of distractors increases, so do age differences in errors and speed, unless the distractors are easily distinguished from the target or unless they occur in predictable locations (Scialfa, Esau, & Joffe, 1998; Zeef, Sonke, Kok, Buiten, & Kenemans, 1996; see Madden & Plude, 1993 for a discussion of sparing factors).

The similarity of environmental distractors to target information also influences age differences in distraction on reading tasks. Both younger and older adults are slower to read a passage of text that has distracting words scattered throughout it than they are to read a control passage without such distraction. However, older adults are more impaired by the distractors than are young adults, and older but not younger adults are further slowed if the distractor words are related to the passage (Carlson, Hasher, Connelly, & Zacks, 1995; Connelly, Hasher, & Zacks, 1991; Duchek, Balota, & Thessing, 1998; Dywan & Murphy, 1996; Li, Hasher, Jonas, Rahhal, & May, 1999) (see Figure 1). As with the target–search tasks described earlier, age differences on the reading-with-distraction task are greatly reduced if the distractors appear in fixed or predictable locations (Carlson et al., 1995).

In other cases, strongly related environmental distractors can lead to age differences even if distractors appear in predictable locations. Furthermore, even young adults can be affected by strongly related environmental distractors, if they are tested at nonoptimal times of day. For example, each trial of the classic Remote Associations Test (RAT; Mednick, 1962) presents participants with three cue words (e.g., ship, outer, crawl), and

[4]For a dramatic illustration, visit www.webpagesthatsuck.com/badtext.htm

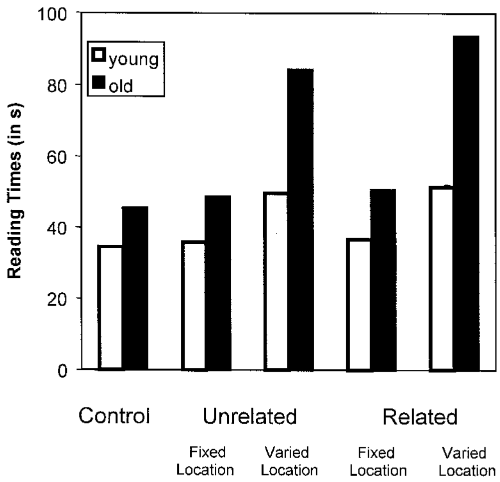

Figure 1. Reading times (in seconds) for younger and older adults in the reading-with-distraction task (from Carlson et al., 1995. Used with the permission of the American Psychological Association).

asks them to find the word that connects them (e.g., SPACE). May (1999) examined how younger and older adults' ability to solve the RAT problems was affected by distractor words presented immediately below the cue words. Two types of distractors were used. "Leading" distractor words (e.g., rocket, atmosphere, attic) had meanings that would help link the cue words with the target. "Misleading" distractors (e.g., ocean, inner, floor) had meanings that would link the cue words with meanings other than the target.

May (1999) hypothesised that, in general, older adults would be less able to ignore the distracting words than would young adults, and thus would show both greater costs from the misleading distractors and greater benefits from the leading distractors. In addition, recent evidence suggests that the ability to control attention fluctuates over the course of the day, with younger and older adults at opposing ends of the circadian cycle (e.g., May & Hasher, 1998; May, Hasher, & Stoltzfus, 1993; see Yoon et al., 2000 for a review). Young adults' inhibitory abilities are at their lowest in the morning and reach a maximum in the late afternoon; older adults' inhibitory abilities are at their highest in the morning and wane throughout the day. Thus, May hypothesised that young adults tested in the morning (their nonoptimal time) would resemble older adults in being affected by distraction, and that older adults tested in the afternoon (their nonoptimal time) would show very large costs and benefits from the misleading and leading distractor words.

May (1999) found that younger and older adults completed an equal number of control problems (i.e., those presented with no distractor words), and that the ability to solve control problems did not change with the time (optimal or nonoptimal) of testing. In contrast, the ability to solve problems presented with misleading or leading distractor words was clearly affected by both age and testing time. Figure 2 illustrates the costs of misleading distractor words and the benefits of leading distractor words, relative to control problems presented without distractors.

Overall, older adults completed more of the problems presented with leading distractors than young adults did, and fewer of the problems presented with misleading distractors. Older adults were less able than young adults to ignore the distractor words, and thus showed both greater costs benefits from distractors. However, for both younger and older adults, the ability to ignore the distractors varied according to whether they were tested at their "good" or "bad" times of day. Young adults tested in the morning showed distraction effects much like those of older adults; in fact, there were no statistically significant age differences in either costs or benefits for participants tested in the morning. For older adults, distraction effects were much greater for participants tested in the afternoon (older adults' nonoptimal time of day) than for participants tested in the morning (older adults' optimal time). Thus, circadian influences on inhibitory control can have dramatic effects on the size of age differences in performance, and even on whether age differences in performance occur (May, 1999).

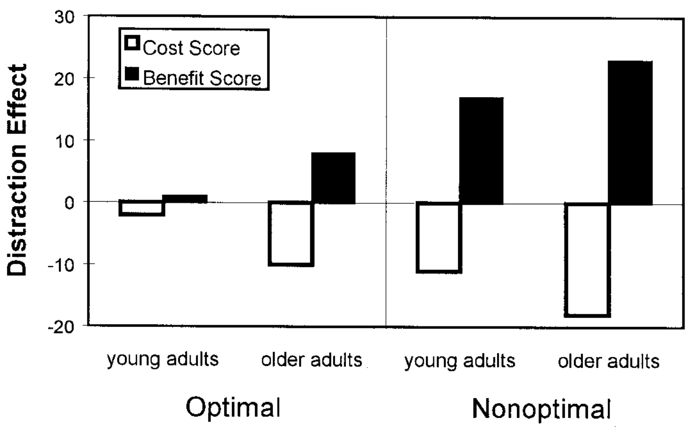

Figure 2. Costs and benefits of distractor words in the Remote Associations Test for younger and older adults tested at optimal and nonoptimal times of day (from May, 1999. Used with the permission of Cynthia P. May and the Psychonomic Society).

For both younger and older adults, extraneous information in the environment can make it difficult to locate, identify, and use target information. This concurrent distraction leads to slowing and errors on a wide range of tasks, from very simple visual attention tasks such as target location to more complex tasks such as solving word problems. Even very well-practised activities, such as reading and driving, are not immune to the effects of distraction, especially at one's "down" time of day. Environmental distractors can have an especially large impact on the performance of older adults, who are less able than young adults to control their attention and keep it away from these distracting, irrelevant stimuli. Older adults' ability to resist distraction can be improved if the distractors are very distinct from the targets or occur in predictable locations, but older adults are particularly vulnerable to distractors that are highly related to the target.

INHIBITORY CONTROL: ITS IMPLICATIONS FOR LIFE IN AND OUT OF THE LAB

Interacting with the world is a complex proposition, with many sources of information simultaneously competing for our attention. In addition to the incoming streams of stimulation from radios, televisions, and mobile phones, internal thoughts and memories may also occupy our minds as we go through the day. The ability to control our attention, keeping it away from irrelevant information so that we can focus on what *is* important, is thus a critical factor for successful performance in many situations.

In this paper, we have for the most part restricted our discussion to the importance of inhibitory control for performance on standard laboratory measures of cognitive function. Older adults' reduced ability to control attention away from irrelevant information plays an important role in determining age differences on many laboratory tasks. Older adults are less able than young adults to avoid keeping thoughts of previous, now irrelevant experience from coming to mind, making it more difficult for them to retrieve the memories that are current and correct for the present situation (e.g., Lustig et al., in press; May et al., 1999a; Winocur & Moscovitch, 1983). Older adults are also more likely than young adults to attend to distracting information present in the environment, which leads to slower performance and an increase in errors (e.g., Carlson et al., 1995; May, 1999; Scialfa et al., 1998).

Inhibitory control—and age differences in inhibition—thus plays an important role in theoretical considerations of attention and memory and how they change with increased age (e.g., Dempster & Corkill, 1999; Gernsbacher & Faust, 1991; Hasher & Zacks, 1988; Hasher et al., 1999; Kuhl, 1992; McDowd, Oseas-Kreger, & Filion, 1995). Indeed, recent evidence

(Lustig et al., in press; May et al., 1999a) suggests that laboratory tasks thought to measure working memory's capacity to simultaneously store and process current information are in fact heavily influenced by participants' ability to avoid the adverse effects of past information. This influence seems to play a critical role in both age differences on these working memory tests and in their ability to predict performance on other cognitive measures. Such a pattern suggests that at least some of the individual and group differences in cognition previously ascribed to differences in working memory capacity may be due to differences in inhibitory control.

The ability to keep attention away from irrelevant thoughts and distraction is also important for everyday life. Memory changes are a major concern for many older adults, and older adults' reduced ability to keep previous, now-irrelevant information out of active consideration impairs their retrieval of the currently desired information (e.g., Lustig et al., in press; May et al., 1999a; Winocur & Moscovitch, 1983). Older adults' difficulty in ignoring environmental distraction can also lead to driving impairments, particularly when they are navigating in a complicated environment or attempting to simultaneously perform other tasks such as using a car phone and carrying on a conversation (e.g., Ball & Rebok, 1994; McKnight & McKnight, 1993; Sekuler, Bennett, & Mamelak, 2000).

These findings have important implications for the ability of older adults to maintain their optimal performance at home and in the workplace. Noisy or visually cluttered environments may be fine for young adults—think of a teenager doing homework in his or her bedroom with the stereo blaring—but older adults may be disrupted by such distraction. This will particularly be the case in the afternoon, when older adults' inhibitory abilities are especially low and those of young adults are at a high point (Yoon et al., 2000).

In short, our perspective is that performance is best when attention is focused on the current task and away from extraneous information. This extraneous information may come either from external sources or from currently irrelevant internal thoughts and memories. Optimal performance depends on the ability to keep this information out of the focus of attention, and age differences in many situations may stem from age-related reductions in inhibitory control.

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