Journal of Gerontology: PSYCHOLOGICAL SCIENCES
2002, Vol. 57B, No. 3, P223–P232

Inhibitory Changes After Age 60 and Their Relationship to Measures of Attention and Memory

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This study examined the relationship between age and inhibitory functioning within a sample of older adults ranging in age from 60 to 85 years old. On the basis of earlier research, and confirmed by factor analysis, measures typically referred to as frontal lobe tasks were used as measures of inhibitory functioning. Findings demonstrated that inhibitory processes continued to decline with advancing age within the older sample. In addition, the role of inhibition in age-related performance deficits on a verbal list learning measure and an attention measure was examined. Hierarchical regression analyses showed that inhibition accounted for a significant proportion of the age-related variance on the two cognitive measures, whereas measures of reading speed accounted for a smaller proportion of the variance. In addition, when inhibition was first covaried out, reading speed no longer accounted for a significant proportion of the age-related variance. It is argued that inhibition is an important contributor to age-related performance decrements in cognition.

An increasingly central notion in attention theory is that inhibitory processes act in concert with excitatory processes to control the contents of working memory. Inhibitory processes help prevent irrelevant stimuli from interfering with the efficient processing of target information in a number of ways (e.g., Hasher & Zacks, 1988; Tipper, 1985; Tipper, Weaver, & Houghton, 1994). Specifically, inhibition can prevent the allocation of attention to irrelevant or distracting information in the internal or external environment, thereby allowing for a focus on the relevant task or goal. Further, as task demands change, inhibition serves to suppress activation of stimuli that were previously important but now are no longer the target of processing (Hasher & Zacks, 1988; Zacks & Hasher, 1994). Finally, more recently it has been proposed that inhibition serves to restrain prepotent responses from occurring immediately, allowing for an initial evaluation as to their appropriateness (Hasher, Zacks, & May, 1999). When inhibitory processes are not operating efficiently, irrelevant or distracting information can invade working memory, possibly resulting in lowered performance due to interference effects and response competition. These interfering effects can occur at both the encoding and retrieval stages.

It has recently been postulated that deficits in inhibitory functioning may account for age-related performance decrements exhibited in a variety of cognitive tasks (Hasher & Zacks, 1988; Hasher et al., 1999; Zacks & Hasher, 1994). This view maintains that inhibitory mechanisms become inefficient with age, causing a disruption to working memory. Working memory has been theorized to be important for successful performance in many cognitive domains, including memory, language comprehension and speech production, and planning and problem solving, among others (Baddeley & Hitch, 1994). Given the importance of working memory to everyday life, any mechanism that affects its efficiency has the potential to affect performance on a wide variety of tasks. There is ample evidence to show that older adults do experience difficulty on many tasks that rely on working memory (e.g., Fisk & Warr, 1996; Glinksy & Judd, 1994; Salthouse, 1994). The notion of inhibition as an explanatory concept for at least part of the difficulties of older adults on working memory tasks has the potential of being a powerful tool for understanding age-related cognitive deficits. Rather than focusing on the possibility that older adults may have reduced capacity for processing information in working memory, this viewpoint proposes that the enhanced access of irrelevant information to working memory makes it difficult for older adults to focus on the relevant information necessary to complete a task or achieve a goal.

Consistent with this view, previous experimental research has demonstrated that in comparison with younger adults, older adults exhibit more difficulty on a variety of tasks for which inhibitory processes have been postulated to be important, including comprehension of text, word-list learning, and the learning of factual information (e.g., Gerard, Zacks, Hasher, & Radvansky, 1991; Hamm & Hasher, 1992; Hartman & Hasher, 1991; Zacks, Radvansky, & Hasher, 1996). For example, the directed forgetting paradigm has been used to demonstrate impaired inhibitory functioning in older adults. In a typical directed forgetting task, a list of words is presented to the participant. Either after each word or after a block of words has been presented, a cue is given that signals whether the participant is to remember or forget the word or words. Each word must be attended to and processed, as the remember/forget cue is not presented until after the word or words are shown. Once the entire list has been presented, the participant is asked to recall all of the remember words. Research has shown that young adults have little difficulty recalling the appropriate words (e.g., Bjork, 1989; MacLeod, 1989). In fact, performance is as good as if the young adults never saw the forget words at all. If asked to recall the forget words, recall is very poor. One explanation for this result is that the younger adults were able to inhibit or suppress the forget words so that they did not interfere with recall of the remember words (Bjork, 1989; MacLeod, 1989). Given this line of reasoning, if older adults have less efficient inhibitory processes as compared with young adults, then they should have more difficulty ignoring those words that were cued as to be forgotten. Results from a study conducted by Zacks and colleagues (1996) supported this prediction. In comparison with a younger group of adults, the older adults recalled fewer of the remember words and made more intrusions from the forget list. In addition, when later asked to recall the forget words, older adults retrieved more of the forget words. These results held regardless of the type of list presented (categorized or uncategorized), timing of the cues (after each word or after a block or words), or the type of memory task used (free recall, recognition, or a speeded response task). It appeared that the older adults had more difficulty than the younger adults did ignoring the forget words when instructed to, with the result that these words interfered more with performance on subsequent recall of the remember words and remained more accessible to the older adults as assessed by a later recall test of the forget words.

Although data such as the above provide substantial support for the inhibition-deficit viewpoint, not all findings are supportive (e.g., Burke, 1997; McDowd, 1997; for a reply see Zacks & Hasher, 1997). One area that demonstrates the complexity of findings on age differences in inhibition is research on negative priming. This phenomenon is observed in selective attention tasks involving a series of trials, on each of which participants respond to (e.g., identify) a target presented along with a distractor. The negative priming effect is the slowed responding to a target that was a distractor on the previous trial as compared with a condition in which the target was not presented on the previous trial. One explanation of this effect is that selective responding to targets involves inhibition of concurrent distractors that carries over to the next trial. Young adults reliably show negative priming effects (May, Kane, & Hasher, 1995; Tipper, 1985). In keeping with the inhibitory view of aging, early studies (e.g., Hasher, Stoltzfus, Zacks, & Rypma, 1991; Kane, Hasher, Stoltzfus, Zacks, & Connelly, 1994) suggested a lack of negative priming effects in older adults. However, more recent research has shown that age differences can be attenuated if not eliminated when task demands are altered. For instance, if the negative priming task requires the individual to make a response based on the location of the stimulus rather than its identity, then older adults will show the same amount of negative priming as younger adults (Connelly & Hasher, 1993; Kane, May, Hasher, Rahhal, & Stoltzfus, 1997). These discrepant findings have led to theories of different inhibitory mechanisms that are differentially affected by the aging process, for example, location versus identity inhibition (Connelly & Hasher, 1993), or inhibitory processes that are associated with the functioning of the frontal lobe (Kramer, Humphrey, Larish, Logan, & Strayer, 1994).

Despite the complex picture that has emerged in some areas of research on age and inhibitory functioning, we believe that the inhibition-deficit viewpoint remains promising (Hasher et al., 1999; Zacks & Hasher, 1997) and is worth pursuing. An extended range of research approaches might be particularly useful to this endeavor. One consideration relating to the current work is that the great majority of evidence on age differences in inhibitory functioning comes from extreme age designs comparing young and old adults. Such studies tell little about whether inhibitory mechanisms contribute to continued age-related decline within an older age group. There is a growing body of evidence to suggest the potential value of a more fine-grained analysis of age differences within the older age range. Using an individual-difference approach, researchers have demonstrated systematic declines across the life span for a variety of tasks including those reflecting information-processing speed (e.g., Nettelbeck & Rabbitt, 1992; Salthouse, 1996) and working memory (e.g., Dobbs & Rule, 1989; Salthouse, 1994). In addition, neuropsychological measures frequently show significant differences between individuals classified as “young-old” (generally defined as the age range of 60–74) and “old-old” (generally 75 and older). The typical finding is that those individuals who are over the age of 75 exhibit lower levels of performance on a variety of neuropsychological measures as compared with those individuals who are between the ages of 60 and 74 (Christensen, MacKinnon, Jorm, & Henderson, 1994; Libon et al., 1994; Osterweil, Mulford, Syndulko, & Martin, 1994).

The few studies that have compared inhibition in young-old and old-old participants present a mixed picture. Arbuckle and Gold (1993; Gold & Arbuckle, 1995) demonstrated that an old-old group exhibited more difficulty on measures they theorized reflected inhibition as compared with a young-old group. In contrast, Balota and Ferraro (1993) and Speiler, Balota, and Faust (1996) did not find strong evidence of differences in inhibitory functioning between these two age groups, although they did find overall the typical pattern of impaired inhibitory processing in the older group as a whole when compared with a younger group of individuals.

The first aim of the current study was to systematically explore inhibitory functioning within an older age range between 60 and 85 by including approximately equal numbers of participants in each 5-year age band. We hoped this design would allow us to further examine inhibitory processes associated with age and extend previous findings on the relationship between age and inhibitory function. On the basis of an important study by Arbuckle and Gold (1993), our study used three neuropsychological tests to measure inhibitory functioning, namely the Wisconsin Card Sorting Test (WCST), the Trail Making Test, and a measure of verbal fluency. As also described by Arbuckle and Gold (1993), choice of these measures was based on arguments and evidence that each of the chosen tasks requires suppression of irrelevant or non-goal-directed information to make an appropriate response.

The WCST (Milner, 1964) requires the participant to first sort cards according to one strategy, and then after a predetermined number of responses the sorting principle changes unbeknownst to the participant who then must alter his or her strategy and attempt to discover the new sorting rule.

For accurate performance, the participant must suppress the initial sorting rule and switch response sets as the demands of the test change (Lezak, 1995). The Trail Making Test (Reitan & Wolfson, 1993) also involves the alternating of response sets. On Trails B of this test, a participant is required to connect letters and numbers sequentially, alternating between the two sets (i.e., 1, A, 2, B, etc.). Once the participant connects a number (or a letter), he or she must inhibit the preceding set to make the next response (to connect a letter or a number). The verbal fluency measure requires the individual to generate as many words as possible that begin with a presented letter within a time limit (Lezak, 1995). The person must inhibit not only items previously generated but also associations with the generated items. Generated items may also activate other related items that are meaningfully associated in some way but are not appropriate to the task (i.e., do not begin with the target letter). Persons who have less efficient inhibitory processes may experience greater response competition due to these activated associations.

Another consideration in the choice of these tasks, although more tenuous, stems from the view that inhibitory functioning may be subserved by the frontal lobes (Dempster, 1992; Kramer et al., 1994). Previous research has demonstrated that patients with frontal lobe dysfunction often show deficits in inhibition (e.g., perseveration and inability to maintain set; for reviews see Cronin-Golomb, 1990; Shimamura, 1995; Stuss & Benson, 1984), leading researchers to theorize that the frontal lobes are important for efficient inhibitory processing (Dempster, 1992; Kramer et al., 1994). It is commonly assumed in the neuropsychological literature that the WCST, verbal fluency test, and Trail Making Test reflect the functioning and integrity of the frontal lobes (e.g., Cronin-Golomb, 1990; Kramer et al., 1994; Lezak, 1995), and by extrapolation one can theorize that adequate performance on these tests may be partially dependent on intact inhibitory processes.

Consistent with these arguments, Arbuckle and Gold (1993; Gold & Arbuckle, 1995) used these three neuropsychological measures as measures of inhibition in their study. The result of a factor analysis showed that these three neuropsychological measures (WCST, verbal fluency, and trails) fell out on one factor, which the authors hypothesized reflected inhibitory functioning. In addition, these researchers were interested in knowing whether inhibition could be a factor in a measure of off-target verbosity. *Off-target verbosity* was defined as an inability to maintain focus; a person would originally respond appropriately to a question or statement but would then begin to talk about other loosely associated or nonrelated (off-target) topics. In this context, off-target verbosity was hypothesized to be a reflection of the inability to inhibit irrelevant information or associations to the questions. Results demonstrated that the neuropsychological measures correlated highly with the measure of off-target verbosity (the higher the off-target verbosity, the lower the scores on the neuropsychological measures), whereas measures of memory (prose passage memory) and simple attention (digit span tests) did not correlate with the off-target verbosity measure.

To validate statistically the choice of the above measures in this study, we first conducted factor analyses to demonstrate replication of Arbuckle and Gold's (1993) findings that the chosen measures loaded on one factor that could be interpreted as reflecting inhibitory functioning. Then, as the second aim of this study, the role of inhibition in age-related performance decrements was examined on a test of verbal-list learning (California Verbal Learning Test, CVLT; Delis, Kramer, Kaplan, & Ober, 1987) and a measure of attention (Paced Auditory Serial Addition Test, PASAT; Gronwall, 1977). There are aspects of both of these tasks that would suggest that inhibition is at least partially responsible for successful performance. In the CVLT, a categorized "shopping list" (A) is presented for learning on five trials, followed by the presentation of a different shopping list (B) for recall on the sixth trial. Participants are then asked to recall the original list once more (short delay) and after 20 min (long delay). Inhibition may be important on both the original learning trials of List A and the recall of A after presentation of List B. During learning, it is important to be able to keep track of responses given across trials. If inhibitory mechanisms are inefficient, this might lead to an increase in repetitions during recall, as well as intrusions of words that are from the same category but not one of the actual words presented on the list. After presentation of List B, the participant must in a sense ignore or inhibit this list to recall the original List A.

Inhibition can also be posited to be important to the completion of the PASAT, a demanding attention task. Numbers are presented one at a time at a brisk pace, and the task is to add each number with the number presented previously and say the total out loud. The trick is to add the two numbers presented and not just keep a running total. On each trial, it is important to delete or suppress from working memory both the earlier presented numbers and the previous total to do the new computation.

Given that inhibition mechanisms are important for a variety of cognitive tasks, it was hypothesized that the inhibition measures would account for a significant proportion of the age-related variance in verbal-list learning and the test of attention. The statistical procedure used to test this hypothesis was a hierarchical regression analysis as described by Salthouse (1991, 1994) and others (Hertzog, 1996). In the current context, the general logic of this approach can be described as follows. If inhibitory deficits are to be invoked as an explanation for age-related performance decrements, then by statistically controlling for measures of inhibition one should be able to account for a significant proportion of the individual age-related variance on cognitive tasks. Specifically, deficits in inhibitory processes should mediate much of the relationship between age and cognitive performance. Therefore, when one statistically partials out inhibition, the zero-order correlation between age and the cognitive measure should be substantially reduced. This statistical procedure has been explained in detail elsewhere (Hertzog, 1996; Salthouse, 1991, 1994).

Of course, factors other than inhibition may also contribute to age-related deficits in cognition. One such factor that has amassed a lot of support is a theory of generalized slowing of information-processing speed (see Salthouse, 1996, for a review). This viewpoint suggests that because of this slowing, those tasks that require rapid on-line processing, which is often a component of working memory tasks, are impaired in older adults. In addition, slowed initial processes cause difficulties in the later stages, not just because of time constraints but also because of the limited or incomplete information that arises from the earlier stages. Because both the CVLT and the PASAT have quick presentation times, it is plausible that processing speed may also be a factor in performance, especially for the older adults.

Salthouse and Meinz (1995) examined the amount of age-related variance accounted for by inhibition for two working memory measures, reading span and comprehension span. These authors used three variants of the Stroop task as the measures of inhibition. They found that inhibition accounted for a significant proportion of the age-related variance in the working memory tasks. However, it was also demonstrated that measures of perceptual processing speed accounted for just as much as—and in some cases slightly more than—the age-related variance in the same working memory measures. As a result, these researchers argued that it was not necessary to invoke inhibitory processes as an explanation for age-related changes in working memory because a cognitive slowing account provided a slightly better model of the data. However, given the fact that there was very little age-related variance in the two working memory measures to be accounted for (reading span = .033; computation span = .018), it is difficult to determine from this one study the relative contributions of cognitive slowing and inhibitory deficits as explanations of age-related declines. Earles and colleagues (1997) also looked at the contribution of inhibition to measures of working memory, with results similar to the Salthouse and Meinz study. Using a negative priming procedure as a measure of inhibition, they did not find that inhibition accounted for much of the age-related variance of the working memory measures. However, measures of interference did account for a significant proportion of the age-related variance in working memory, measures that have also been used in the literature as measures of inhibition (i.e., Stroop interference score and the reading with distraction task). In addition, it was demonstrated that processing speed was a significant contributor to the age-related changes on the inhibition and interference measures; however, the role of processing speed and working memory was not directly assessed in this study.

Given the mixed results regarding the relative contribution of processing speed and inhibition to cognitive changes with age, the present study attempted to further delineate the role of inhibition and cognitive slowing in age-related performance decrements on the verbal-memory task and complex-attention task.

For this study, reading speed was used as a measure of processing speed. In particular, a composite of two measures of reading speed, word reading and prose reading, was used. Although not the typical measure of processing speed, reading speed has been used in previous studies as an indicator of processing speed (Hartley, Stojack, Mushaney, Annon, & Lee, 1994; Hultsch, Hertzog, & Dixon, 1990; Hultsch, Hertzog, Small, McDonald-Miszczak, & Dixon, 1992; Salthouse & Meinz, 1995). For example, the Salthouse and Meinz (1995) study discussed above used a measure of reading speed along with the usual perceptual-speed measures. Their findings showed the same pattern of results for both speed measures, suggesting that reading speed can be used as a gauge of processing speed.

Methods

Participants

One hundred older volunteers were recruited from the greater Lansing, Michigan, area. Fifty men and 50 women were assessed. However, 8 participants were unable to complete all of the tasks because of vision difficulties (2), poor reading comprehension (1), refusal (1), and our inability to administer all of the tasks because of time considerations (4). The following analyses are based on the remaining 92 participants. The participants were recruited from three local churches and the Foster Grandparents Association. A donation of $10.00 was made to the church for every person who volunteered for this project. As an added incentive, for every 20 volunteers recruited from the same church, an additional $50 was donated. Volunteers from the Foster Grandparents Association were paid $12 for their participation.

Mean age of the sample was 72.74 (SD = 7.09; range = 60–85), with a mean education of 13.65 years (SD = 2.43; range = 8–20). No participants were excluded on the basis of the presence of dementia as measured by the Mini-Mental State Examination, with all participants scoring above the cutoff of 23 on this test (Folstein, Folstein, & McHugh, 1975; M = 27.9, SD = 1.72; range = 24–30). To study the relation of age and inhibitory functioning, we recruited approximately equal numbers of individuals across five age ranges. Age and respective education levels are reported in Table 1. Education levels were found to not differ significantly across age groups on a one-way analysis of variance, $F(4,87) = 2.03$, $MSE = 5.65$. Presence of depression in this sample was assessed with the Geriatric Depression Scale (GDS; Brink et al., 1982). No one was excluded on the basis of this measure. The mean GDS score was 3.46 (SD = 2.88, range = 0–12). Only three of the sample could be classified as having mild depression (GDS $\geq$ 10) as measured by this self-report questionnaire.

Participants in this study were tested individually in their homes or at the university with sessions lasting approximately 3.5 hr. The measures discussed in this article were presented in a fixed order along with additional measures administered for other purposes. Specifically, the order of administration was as follows: PASAT, WCST, word reading, Vocabulary subtest, Trail Making Test, verbal fluency, CVLT, and prose reading. Approval for this study was ob-

Table 1. Means and Standard Deviations of Age and Education for 92 Older Individuals

		Age		Education	
Age Range	*n*	*M*	*SD*	*M*	*SD*
60–65	18	62.44	1.69	15.00	2.99
66–70	19	68.57	1.39	13.58	2.17
71–75	20	72.85	1.57	13.25	2.15
76–80	20	78.30	1.38	13.50	2.48
81–85	15	82.80	1.52	12.87	1.88

tained from the Human Subjects Review Committee at Michigan State University.

Measures

Trail Making Test (Reitan & Wolfson, 1993).—The Trail Making Test from the Halstead Reitan Neuropsychological Battery is composed of two components. Trails A required the participant to draw a line connecting 25 numbers, in order. Trails B, in contrast, presented a page of numbers and letters, and the individual's task was to alternate between the numbers and letters in order. Time to complete both parts was recorded as well as number of errors. To control for differences in visuomotor ability, we calculated Trails B − Trails A and used the result in the subsequent analyses. A higher score represents more difficulty on this task.

WCST (Heaton, Chelune, Talley, Kay, & Curtis, 1993; Milner, 1964).—The participant was given a set of 128 cards on which were printed one to four symbols of either stars, crosses, triangles, or circles in one of four different colors. The task was to place each of the cards under one of four stimulus key cards according to a principle that the person must deduce from the pattern of the examiner's responses to the person's placement of the cards (i.e., color, form, or number). After a run of 10 correct placements in a row, the examiner shifted the to-be sorted principle, indicating the shift to the participant only in the changed pattern of his or her "right" and "wrong" statements. This was continued until six category shifts were achieved or all cards were used. Strategy formation and the ability to flexibly change response sets were measured by the number of perseverative responses (defined as a repetition of an incorrect strategy despite feedback) from the WCST, using the Heaton scoring system, with higher scores representing greater impairment.

Controlled Oral Word Association or Verbal Fluency (Benton & Hamsher, 1989; Lezak, 1995).— Participants were asked to generate as many words as possible in 1 min that began with a certain letter. Three separate letters were administered, C, F, L, and the total number of words generated for all three letters was summed. Lower scores on this task represent greater difficulty.

Prose reading.—The mean time to read a series of short stories was used as a measure of reading speed. The stories, taken from Connelly, Hasher, and Zacks (1991) were presented in italic print and were approximately 125 words in length. Font was large (14 point) to compensate for visual problems commonly experienced by older individuals. Participants were instructed to read each story accurately and carefully out loud, starting with the title, and were told that four multiple choice questions about the story would follow each passage. Time to read each story was recorded, and a mean reading time was calculated.

Word reading (Golden, 1978).—The word reading condition from the Stroop Color–Word Task was used for this measure. Participants are asked to read out loud words that are presented on a card (the words blue, red, and green). The number of words read in 45 s was recorded.

CVLT (Delis et al., 1987).—A 16-item categorized list was presented for learning (i.e., Monday's shopping list consisting of four words from each of four different categories: vegetables, clothing, tools, and spices and herbs). The list was read out loud five times with instructions to recall as many words as possible after each presentation. Total number of words recalled over the five trials was recorded. Although the complete test was administered, some of the other measures that could be argued to reflect inhibitory functioning, such as the number of perseverations (repetitions of words already recalled) during list learning, had a restricted range of responses (consistent with normative data). The lack of variability precluded their use in regression analyses. As a result, for the purposes of this study, only total recall was used in the subsequent analyses.

PASAT (Gronwall, 1977).—A recorded tape presented a string of numbers at predetermined intervals, and the task was to add each number to the number that was presented just before it, saying the total out loud (Gronwall, 1977; Lezak, 1995). Four blocks of 61 digits were administered. Presentation times per digit were decreased across the four successive blocks. Presentation time of the first block was 2.4 s per digit, and then the times were 2.0 s, 1.8 s, and 1.4 s for the three additional blocks. Once a response has been given, the individual must in a sense "forget" or suppress the total he or she has just said out loud, to generate the next response (which is to add the new number to the previous number presented). Total number correct was recorded.

Vocabulary subtest (Wechsler, 1981).—The Vocabulary subtest from the Wechsler Adult Intelligence Scale—Revised (WAIS–R) was also administered. Because vocabulary level can influence performance on a number of the above tasks, administration of this test allowed us to statistically partial out the effects of verbal ability in the following analyses.

Results

Unless otherwise specified, an alpha level of .05 was used for all the statistical tests. Descriptive data on the measures are presented in Tables 1 and 2. For this sample, the mean vocabulary score was 48.49 (SD = 9.66, range = 21–65) out of a possible 70 points. The results from the multivariate analyses of variance for age and gender are shown in Table 2. Significant age differences were seen for all of the measures except for the verbal fluency score and word reading. Gender differences were exhibited just on two measures, prose reading (p = .011) and the CVLT (p = .001). Inspection of the data showed that the men were faster in prose reading, whereas the women performed higher on the CVLT. None of the Age × Gender interactions were significant. Because partialing out gender in the regression analyses for the CVLT did not significantly change the pattern of results, the nonpartialed regression analysis is reported here.

A principal-component factor analysis with varimax rotation was performed with the three inhibition measures. The analysis showed that one factor had an eigenvalue of 1.67,

Table 2. Means and Standard Deviations for the Neuropsychological Tests Administered to 92 Older Individuals

Test Measure	All Ages	Age in Years				
		60–65	66–70	71–75	76–80	81–85
Vocabulary Score (WAIS-R)	48.49 (9.66)	52.94 (6.65)	47.63 (10.26)	46.4 (9.23)	50.5 (8.98)	44.33 (11.64)
Verbal Fluency Total Score	37.07 (11.66)	41.39 (11.85)	37.32 (12.49)	36.75 (12.39)	38.2 (6.62)	30.47 (9.89)
WCST Perseverative Responses[a, b]	22.24 (19.23)	11.44 (8.71)	21.79 (15.11)	24.85 (18.87)	22.25 (17.53)	32.27 (29.17)
Trails B − Trails A[a, b]	63.63 (34.65)	45.06 (22.81)	52.16 (29.79)	64.0 (36.23)	73.0 (26.53)	87.47 (44.05)
CVLT Total Recall Over 5 Trials[b, c]	41.34 (10.04)	47.56 (10.92)	43.11 (8.59)	42.05 (7.82)	39.25 (8.89)	33.47 (9.89)
PASAT[b]	92.61 (45.18)	118.89 (34.28)	99.63 (46.08)	95.7 (42.77)	86.0 (39.89)	56.87 (45.49)
Prose Reading Time[a, b, c]	56.45 (17.80)	46.44 (6.22)	57.4 (17.16)	54.33 (11.49)	59.17 (18.65)	66.47 (26.99)
Word Reading	89.70 (15.89)	96.72 (12.92)	90.05 (21.66)	88.4 (11.7)	89.6 (16.98)	82.67 (11.82)

Notes: Values are mean (*SD*). WCST = Wisconsin Card Sorting Task; CVLT = California Verbal Learning Test; PASAT = Paced Auditory Serial Addition Test.
[a]Higher scores reflect poorer performance.
[b]MANOVA significant age differences; $p < .05$.
[c]MANOVA significant gender differences; $p < .05$.

accounting for 55.5% of the variance. The factor loadings for the individual variables were .77, −.71, and .75, for Trails B − A, the verbal fluency score, and the perseverative response score, respectively. This single factor was interpreted as reflecting inhibitory processes on these tasks. The loadings of the neuropsychological measures on this factor were very consistent with the factor loadings reported by Arbuckle and Gold (1993; in their sample the factor accounted for 54.6% of the variance with individual loadings of .78, −.70, and .73).

Table 3 shows the correlations between age and the various test measures. As can be seen from these correlations, even though all of our participants would typically be classified as elderly, age was significantly associated with the inhibition measures, suggesting that inhibitory functioning changes with advancing age beyond 60 years. Age also accounted for a significant proportion of the variance on both the CVLT and the PASAT (upper portion of Table 4; see also correlations in Table 3). These results are consistent with previous research showing continued age declines in performance beyond age 60 (Delis et al., 1987; Roman, Edwall, Buchanan, & Patton, 1991).

To examine the role of inhibition in performance on the CVLT and PASAT, we performed hierarchical regression analyses, first looking at the amount of age-related variance in these two measures and then examining the amount of variance left after the inhibition measures were partialed out. Results from the hierarchical regression analyses and the order of entering the variables into the equation are presented in Table 4. First, we partialed out vocabulary level and education, as these variables have been shown to correlate with performance on the CVLT (Lezak, 1995) and PASAT (Roman et al., 1991; Van Zomeren & Brouwer, 1994). Once education and vocabulary levels were partialed out, one can see by inspection of the table that age still accounted for a significant portion of the variance of both the CVLT total-recall score and PASAT ($R^2 = .142$ and .101, respectively). Next the inhibition measures were entered as a group into the regression analyses, and the remaining variance due to age was examined. As can be seen from Table 4, after partialing out the inhibition measures, the age-related variance on both the CVLT and the PASAT was substantially reduced. Similar results were obtained when the factor scores of the inhibition measures were partialed out. The results from these analyses lend support for the role of inhibitory processes in performance on these standardized measures of memory and attention.

As an alternative to considering inhibitory deficits as an explanation for the majority of the age-related variance in the memory and attention measures, the possible role of

Table 3. Correlations Among Age and the Neuropsychological Measures

Variable	1	2	3	4	5	6	7	8	9	10
1. Age	—									
2. Education	−.26*	—								
3. Vocabulary	−.20	.45*	—							
4. Verbal Fluency	−.24*	.30*	.44*	—						
5. Trails B − A	.45*	−.27*	−.41*	−.32*	—					
6. WCST pers	.30*	−.20*	−.20*	−.29*	.38*	—				
7. RD baseline	.34*	−.29*	−.60*	−.31*	.36*	.30*	—			
8. Word Reading	−.24*	.44*	.46*	.53*	−.36*	−.36*	−.55*	—		
9. CVLT total score	−.44*	.26*	.26*	.30*	−.44*	−.35*	.22*	.41*	—	
10. PASAT	−.40*	.25*	.38*	.36*	−.46*	−.36*	−.34*	.47*	.49*	—

Note: WCST pers = perseverative responses from the Wisconsin Card Sorting Task; RD baseline = Reading with Distraction baseline reading score; CVLT = California Verbal Learning Test; PASAT = Paced Auditory Serial Addition Test.
$*p < .05$; $n = 92$.

Table 4. Results From the Hierarchical Regression Analyses

Regression and Controlled Variable	CVLT Total Recall R^2	CVLT Total Recall Increase in R^2	PASAT R^2	PASAT Increase in R^2
1				
Vocab and Ed	.095*		.150*	
Age	.236*	.142*	.251*	.101*
2				
Vocab and Ed	.095*		.150*	
Inhibition Measures	.260*	.165*	.305*	.155*
Age	.311*	.051*	.334*	.029
3				
Vocab and Ed	.095*		.150*	
Factor scores	.250*	.156*	.301*	.151*
Age	.309*	.058*	.334*	.032*
4				
Vocab and Ed	.095*		.150*	
Speed Composite	.146*	.051*	.227*	.077*
Age	.256*	.110*	.294*	.067*
5				
Vocab and Ed	.095*		.150*	
Speed Composite	.146*	.051*	.227*	.077*
Inhibition Measures	.269*	.123*	.327*	.101*
Age	.355*	.059*	.351*	.023
6				
Vocab and Ed	.095*		.150*	
Inhibition Measures	.260*	.165*	.305*	.155*
Speed Composite	.269*	.009	.327*	.022
Age	.316*	.047*	.351*	.023

Note: CVLT = California Verbal Learning Test; PASAT = Paced Auditory Serial Addition Test; Vocab and Ed = vocabulary and education.

$*p < .05$.

processing speed was examined. The correlation between word reading and prose reading was −.55 (−.60 after correction for unreliability; controlling for the effects of gender did not affect this correlation, which was then −.54). A *z* score composite was created by taking the average of the *z* scores of the word-reading and prose-reading scores. The *z* score composite was entered into the hierarchical regression analysis before age was entered. As can be seen from Table 4, although there was a reduction in the associated age-related variance in the memory and attention measures, the reading speed composite score did not numerically account for as much of the age-related variance in the two measures as the inhibition measures did. To further examine the relative roles of reading speed and inhibition, we entered the speed composite score into the equation before inhibition. Even after we accounted for speed, the inhibition measures still explained a significant proportion of the age-related variance in both the CVLT and PASAT. When inhibition was first entered into the equation, speed was no longer a significant predictor of the age-related variance.

Discussion

Two major findings from this study need to be emphasized concerning the relationship between inhibitory processes and aging. First, these results show that inhibitory functioning continues to become less efficient with advancing age, even within an older population. These findings closely replicate and extend those of Arbuckle and Gold (1993), who found that the old-old group performed worse on the inhibition measures than a young-old group (Gold & Arbuckle, 1995). Unlike the findings in the majority of studies, which have focused on the differences in inhibitory functioning between younger and older participants, these findings suggest a decline in the efficiency of inhibitory processes associated with the aging process. This result is consistent with other studies that have focused on decreases in cognitive functioning within the older age range (Christensen et al., 1994; Osterweil et al., 1994). Unlike the present findings, results from two earlier studies that addressed inhibitory functioning in a young-old versus an old-old group did not provide strong evidence for a decline in inhibition with advancing age (Balota & Ferraro, 1993; Speiler et al., 1996). However, both studies used wider age ranges for their older age groups that may have attenuated differences in inhibitory functioning between young-old and old-old groups, masking age-related changes.

The second major finding from this study lends further support for the role of inhibition in cognitive declines associated with aging, specifically on a test of verbal-list learning (CVLT) and a test of attention (PASAT). The age-related variance on these tasks was substantially attenuated when measures reflecting inhibitory functioning were statistically partialed out. These findings show the importance of declines in inhibitory processes as a mediator of age changes in cognition, consistent with previous research (see Hasher et al., 1999; Zacks & Hasher, 1994). Although the speed composite score did account for some of the age-related variance, the inhibition measures numerically accounted for a greater proportion on both the memory and attention measures. These results are different from those reported by Salthouse and Meinz (1995). In their study, they found that measures of cognitive speed accounted for as much of—and in some cases more than—the age-related variance on two measures of working memory. One possible explanation for the discrepant results is that the age-related variance to be accounted for in the verbal memory and attention measures was somewhat larger in this study (.142 and .101, respectively, after controlling for vocabulary and educational influences) than in the Salthouse and Meinz study (.033 and .018, for the two measures of working memory span). As a result, the differential effects of inhibition and cognitive slowing may have been easier to detect. On the other hand, the measures that were used in this study to compute the speed composite score may not have been optimal measures of cognitive speed of processing. The use of other tasks reflecting cognitive slowing, such as those used by Salthouse and Meinz, may have yielded different results.

Even though the inhibition measures accounted for a greater proportion of the variance, the speed measures were still an added significant mediator of performance decrements with age. The findings of both processing speed and inhibition as important contributors to performance on our tests of attention and memory support the results of more recent studies. Kwong See and Ryan (1995) demonstrated that measures of perceptual speed and inhibition were independent predictors of the age-related variance in a battery of language tasks in older adults. West and Baylis (1998) also demonstrated differential effects of processing speed and inhibition in different versions of the Stroop task.

Although this study has provided evidence that inhibition is an important factor in age-related cognitive declines, other individual difference variables may also play a role. The recruitment process used in this study was an attempt to enlist older individuals living in the community (who normally would not volunteer for research studies) in hopes of assessing a more representative sample. As a result, many of the volunteers had less than a college education and exhibited average ability on the vocabulary test. This sample may be different from those older individuals who answer advertisements in the newspaper on variables such as education and vocabulary knowledge. As opposed to the exceptionally healthy older individuals often used in aging research, the more average characteristics of our sample may have contributed to their showing an obvious effect of decreased inhibition on cognitive functioning. These individual differences, generally ignored in relation to inhibition, may partially account for the strong findings of reduced efficiency in inhibitory mechanisms. There is some suggestion that individual-difference variables can partially account for inhibitory functioning even in young adults. For example, in one study, Gernsbacher (1993) found that in comparison with skilled readers, less skilled young adult readers showed reduced suppression on reading comprehension tasks requiring the suppression of inappropriate meanings of ambiguous words. On the basis of these findings, it would be important to further study the role of individual differences in the efficiency of inhibitory functioning. A more systematic approach that attempts to measure and control for other individual variables, such as reading skill or health status, is necessary to understand the impact of individual-difference variables on inhibitory functioning. However, as a first step to addressing these issues, vocabulary ability and educational level of the participants were statistically controlled for in our regression analyses, with results demonstrating that inhibition remained an important factor, accounting for a significant proportion of the age-related decline on the memory and attention tests.

As a final point, the choice of frontal lobe measures in this study as the index of inhibitory functioning leads to the question of whether age-related declines in inhibitory functioning can be localized to the frontal system. Evidence lending some support to this claim comes from a number of different sources. The neuropsychological literature reports numerous results of patients presenting with lesions of the frontal lobes exhibiting deficits in inhibition (for reviews see Cronin-Golomb, 1990; Stuss & Benson, 1987). These patients typically experience difficulty switching response sets, have more perseverations, and are easily distracted (Lezak, 1995). With respect to the older population, older individuals have been reported to evidence similar difficulties on these frontal lobe measures, although to a lesser degree (West, 1996). For example, older adults demonstrate more perseverations on the WCST as compared with younger adults (Heaton et al., 1993). When cognitive tasks are chosen to reflect the integrity of a number of different brain regions, older adults show differentially more impairment on tasks of frontal lobe functioning (Daigneault, Braun, & Whitaker, 1992; Mittenberg, Seidenberg, O'Leary, & DiGiulio, 1989) as opposed to those tasks that tap the integrity of other brain regions. Just as results from cognitive studies suggest a differential decline in frontal lobe functioning associated with aging, evidence from neuropathological and neuroimaging studies also support this contention. Atrophy is greater in the frontal lobes as compared with other cortical regions (Haug & Eggers, 1991), and a reduction in cerebral blood flow in the frontal lobes has also been reported in older individuals (Gur, Gur, Obrist, Skolnick, & Reivitch, 1987). In an evoked potential study, Chao and Knight (1997) demonstrated changes in the frontal lobes in older adults during a task that was theorized to require inhibitory processes for successful performance.

Taking all of the evidence into account, there is some support that inefficient inhibitory processes in the older population are related to the functioning of the frontal lobes. This has been suggested by other researchers (e.g., Dempster, 1992; Kramer et al., 1994; Shimamura, 1995), and the results from this study fit within this framework. The proposal of inhibitory changes related to frontal lobe functioning to explain cognitive deficits could lead to a richer theory of aging. With a few exceptions, the frontal lobe hypothesis of aging has been mainly descriptive in nature. The inclusion of an inhibitory mechanism can lead to more specific and testable hypotheses. Depending on the nature of the task, and the relative role of inhibition to successful performance, age deficits would be expected to different degrees.

In summary, the results of this study lend further evidence that inhibitory functioning declines with advancing age and can affect a range of cognitive domains of functioning, including verbal memory and attention. The finding of a decrease in inhibitory functioning within an older population highlights the need for future studies to go beyond simple comparison studies of inhibition between young and old participants, and examine more fully the relationship of inhibitory processes and cognition across a more extended age range. In addition, the findings of both inhibition and processing speed as significant and independent mediators of age changes in cognition suggest that there are multiple determinants of performance decrements with age.

Acknowledgments

Carol Persad received a Student Research Award from Adult Development and Human Aging, Division 20 of the American Psychological Association and the Retirement Research Foundation for this study. The study was supported in part by National Institute on Aging Grant AGO 4306 to Lynn Hasher and Rose Zacks. We thank Lynn Hasher for comments on an earlier draft and Julie Daugherty for her assistance with data collection.

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Received October 7, 1998
Accepted November 24, 2000
Decision Editor: Toni C. Antonucci, PhD