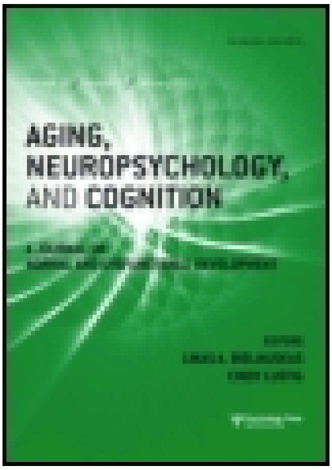

Aging, Neuropsychology, and Cognition: A Journal on Normal and Dysfunctional Development

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/nanc20

Age differences in inhibition: Possible causes and consequences

Julie L. Earles [a] , Lisa Tabor Connor [b] , David Frieske [c] , Denise C. Park [c] , Anderson D. Smith [d] & Melissa Zwahr [c]

[a] Furman University ,

[b] Boston University School of Medicine ,

[c] University of Georgia ,

[d] Georgia Institute of Technology ,

Published online: 25 Sep 2007.

Aging, Neuropsychology, and Cognition
1997, Vol. 4, No. 1, pp. 45-57
1382-5585/97/0401-45$12.00

Age Differences in Inhibition: Possible Causes and Consequences*

Julie L. Earles[1], Lisa Tabor Connor[2], David Frieske[3], Denise C. Park[3], Anderson D. Smith[4], and Melissa Zwahr[3]
[1]Furman University, [2]Boston University School of Medicine, [3]University of Georgia, and [4]Georgia Institute of Technology

ABSTRACT

The relations among age, inhibition, perceptual speed, susceptibility to interference, and working memory were examined in a sample of 301 adults age 20 to 90. Younger adults were found to have more efficient inhibitory mechanisms than were older adults. Significant inhibition, however, was found in all age groups, including the older age group. Older adults were also found to be more susceptible to interference from irrelevant information. There was a small negative relation between interference and inhibition, suggesting that participants with the most efficient inhibitory functioning may be the least susceptible to interference. Perceptual speed, an index of processing efficiency, was found to mediate nearly all of the age-related variance in inhibition and interference. Interference, but not inhibition, was found to mediate some of the age-related variance in working memory.

Age-related changes in the efficiency of inhibitory functions in the attentional system have been hypothesized to contribute to age differences in working memory (Hasher & Zacks, 1988). Hasher and Zacks (1988) proposed that changes in working memory function with increased age may be due to two processes: (a) a decreased ability to inhibit or prevent irrelevant information from entering into working memory, and (b) an increase in the susceptibility to interference or distraction from irrelevant information. A malfunction of inhibitory functions, therefore, is hypothesized to allow irrelevant information into working memory leading to poorer memory performance. Not only is more irrelevant information allowed into working memory but, in addition, once this irrelevant information is in working memory, it may remain in working memory longer for older than for younger adults (May, Kane, & Hasher, 1995). Because a malfunction in the inhibitory system allows irrelevant information to be present in working memory, it may lead to an increase in interference from this irrelevant information. Thus a decrease in inhibitory function may contribute to age differences in susceptibility to interference. One consequence of these changes may be poorer working memory function.

One paradigm used to measure inhibitory function in selective attention is the negative priming paradigm. Negative priming refers to an

* This research was supported by a grant from the National Institute on Aging (RO1-AG06265) to Denise Park and Anderson Smith. Julie Earles and Lisa Connor were supported by National Institutes of Health Institutional Research Training Grant T32 AG00T75 from the National Institute on Aging to the School of Psychology, Georgia Institute of Technology. The authors gratefully acknowledge substantial contributions to this research from Lynn Hasher, Rose Zacks, Cynthia May, and Michael Kane, who provided helpful assistance on task development and design. We also thank Steven Tipper for advice on task development.
Address correspondence to: Julie L. Earles, Psychology Department, Furman University, Greenville, SC 29613, USA. E-mail: earles_julie/furman@furman.edu.
Accepted for publication: August 9, 1996.

increase in response latency to a target object when that same object was previously a distractor object that was to be ignored (May et al., 1995; Tipper, 1985). In other words, people are slower to respond to an item if they have previously suppressed a response to that item because the suppression dissipates slowly (May et al., 1995).

Age differences in negative priming have been found in many studies (e.g., Hasher, Stoltzfus, Zacks, & Rypma, 1991; Kane, Hasher, Stoltzfus, Zacks, & Connelly, 1994; McDowd & Oseas-Kreger, 1991). Although younger adults are consistently slower in naming a target after previously ignoring it, older adults often fail to show such an effect (e.g., Hasher et al., 1991; Kane et al., 1994; Stoltzfus, Hasher, Zacks, Ulivi, & Goldstein, 1993; Tipper, 1991). That is, older adults are often just as fast (or faster) to respond to a target that was ignored on a previous trial as to a target that was not ignored on a previous trial. Thus increased age is associated with less efficient inhibitory functioning. The decline in the ability to inhibit irrelevant information may result in an increase in information in working memory, thus decreasing working memory efficiency.

Related to problems with inhibitory processes, there is much evidence that older adults are more susceptible to interference than are younger adults. For example, age differences have been found in performance on the Stroop Color and Word Test. In this task, participants are asked to name the colors of series of *x*es printed in colored ink and to name the colors of color words (i.e., red, blue, green) that are printed in colored ink that is incompatible with the word. Older adults are especially slowed when naming the color of incompatible color words as compared to naming blocks of colored *x*es (e.g., Dulaney & Rogers, 1994). Older adults are also more distracted by irrelevant information while reading text passages. Connelly, Hasher, and Zacks (1991) found that older adults were more disrupted than younger adults when reading passages with irrelevant information inserted. In addition, older adults have been found to produce more intrusions of nonpresented items during recall tests than do younger adults (e.g., Cohen, 1988).

Interference has also been measured within the same selective attention paradigm that has been used to measure inhibition. Response interference can be examined by measuring the difference in the response latency to targets presented with a distractor and the response latency to targets presented alone (Hasher et al., 1991). When using this paradigm, conflicting results have been found (e.g., Stoltzfus et al., 1993; Tipper, 1991). Stoltzfus et al. (1993) hypothesized that decreased inhibitory function should be related to increased interference. They did not, however, find a significant effect of age on interference or a significant correlation between negative priming and interference within the selective attention paradigm. They also failed to find significant relations between negative priming and performance on the Stroop and Reading Distraction tasks. Kane et al. (1994) did find a significant negative correlation between inhibition and interference, but only for older adults, whereas Sullivan and Faust (1993) found a significant negative correlation between inhibition and interference for both younger and older adults.

Inhibition and interference may not be directly related because they may affect different parts of the selective attention task (May et al., 1995). May et al. (1995) present evidence that the negative priming effect occurs after selection of the target and serves to maintain a distinction between relevant and irrelevant information. Inhibition may affect the response phase in a selective attention task by maintaining the activation of the target by reducing attention to already rejected items (Kramer, Humphrey, Larish, Logan, & Strayer, 1994; Stoltzfus et al., 1993). Older adults may have more difficulty abandoning this irrelevant information than do younger adults (Stoltzfus et al., 1993).

May et al. (1995) suggest that the interference, or distraction, effect may take place during selection, interfering with the participant's ability to select a target among the distractors. Interference, therefore, may take place while one is choosing to which stimulus to respond, and inhibition may take place after selection when one has to make a response while preventing another response. Alternatively, inhibition may have effects on both the selection and the response phase of the task. Inhibition may help reduce interference during selection by suppressing attention to the previous distractor. Inhibition may then influence the response phase by suppressing a response to the previous distractor. Thus a decrease in inhibition may lead to an increase in interference.

Age-related declines in perceptual speed, an index of processing efficiency, may contribute to age differences in inhibition that then lead to age-related increases in susceptibility to interference. Thus, perceptual speed may mediate the age-inhibition and age-interference relations. As people get older, they are slower to process information and may be slower to inhibit irrelevant information as well. Perceptual speed has been found to affect working memory by influencing the rate of activation of information (Salthouse, 1992). It is hypothesized that age-related decreases in speed contribute to age differences in inhibition and interference that then affect the rate of activation of relevant information in working memory, thus contributing to age differences in working memory.

Supporting the notion of a relation between processing efficiency and inhibition, Engle, Conway, Tuholski, and Shisler (1995) found that negative priming is decreased when mental workload is increased. Also, Neumann and Deschepper (1992) found that faster participants show greater negative priming than do slower participants. Active suppression of irrelevant information seems to be influenced by processing speed.

Age-related decreases in processing speed may, therefore, contribute to age-related declines in inhibition and interference. In support of this hypothesis, Salthouse and Meinz (1995) found that age differences in Stroop interference are related to age differences in processing speed. Contrary to the findings of Neumann and Deschepper (1992), however, McDowd and Oseas-Kreger (1991) found no evidence for negative priming even among their fastest older adult subjects but found negative priming in their slowest younger adult subjects.

There is evidence that inhibitory function does not just take longer to build for older adults than for younger adults. May et al. (1995) suggest that if inhibition simply takes longer to build for older adults, then older adults should show negative priming at longer intervals from presentation. Stoltzfus et al. (1993), however, found no negative priming for older adults even 1,700 ms after the response. Also, Kane et al. (1994) used a longer stimulus exposure duration (i.e., 500 ms) in an attempt to compensate for slower processing on the part of older adults, but still did not find negative priming by older adults. Thus inhibition may not only be slower to build for older than for younger adults. Instead, there may be a real decrease in inhibitory functioning.

Age differences in many tasks are not eliminated by providing additional time (e.g., Storandt, 1977), and processing speed is found to be associated with large amounts of the age-related variance in many nonspeeded tasks (e.g., Salthouse, 1994). Older adults may not inhibit information as well as younger adults as the result of a more general slowing phenomenon. One effect of a less efficient system may be a less efficient inhibitory mechanism. Salthouse and Meinz (1995) provide some evidence for this theory. They found a significant relation between interference and processing speed and also found evidence that suggests that the relation between interference and working memory is due to an association with processing speed.

Thus age-related decreases in processing speed may result in less efficient inhibitory functioning and increased susceptibility to interference that lead to a decrease in working memory efficiency among older adults. The purpose of the current study was to examine the relations among age, perceptual speed, inhibitory function, susceptibility to interference, and working memory, using a large sample of adults age 20 to 90. It was hypothesized that there would be age differences in one measure of negative priming and in four measures of interference. It was also hypothesized that age differences in perceptual speed would be related to age differences in inhibition and interference, which in turn would be related to age differences in working memory.

METHOD

Participants

Participants were 301 adults age 20 to 90 who participated in Park et al. (in press). All participants were community dwelling adults who received $50 upon completion of the entire study. The characteristics of these participants are shown in Table 1. There were significant correlations between age and education and between age and vocabulary, both favoring the older adults. There were significant correlations between age and self-rated health and between age and number of medications, both favoring the younger adults. All age groups, however, rated their health as between good and excellent.

Procedure

Negative Priming for Words Task

Participants were seated in a dimly lit room in front of a Macintosh IIci computer equipped with a Gerbrands voice-activated relay system. This relay system allowed for the recording of response times for a vocal response to the nearest millisecond. The task is similar to a task used by Kane et al. (1994). Participants were presented with words on a computer screen, and were instructed to name aloud the word that appeared in green (i.e., the target word) and to ignore the word that appeared in red (i.e., the distractor word). The words used were *bag, cat, cup, fun, gin, jar, pot, rod*, and *tie*. Each word pair was 6 mm in height and was presented in the center of a white computer screen.

There were three types of trials: control trials, ignored repetition trials, and no distractor trials. Each trial consisted of a prime screen followed by a probe screen. The prime screen was identical for each of the three types of trials. Participants saw two words on the screen, a target word in green and a distractor word in red. The probe screen differed for the three types of trials. On control trials, the probe screen contained two new words, a green target and a red distractor. On ignored repetition trials, the probe screen contained the previously irrelevant word (i.e., the red distractor word) as the target (i.e., the green word) and presented a new word as the red word that was to be ignored. On the no distractor trials, the probe screen contained only a new green target word. A summary of the trials is presented in Table 2.

Eighteen practice trials were followed by six blocks of 18 experimental trials. There was a total of 36 trials of each type. A trial proceeded as follows: (a) The participant saw a screen with the word *Ready?* and responded verbally when ready to begin; (b) a fixation sign, +, was presented for 500 ms; (c) the prime screen green and red words were presented for 300 ms; (d) a mask made up of a fine grating of black dots replaced the words for 100 ms; (e) a blank screen was presented for 1100 ms to allow the participant to name the green word; (f) a second fixation sign, +, was presented for 250 ms; (g) the probe green and red words were presented for 300 ms; (h) the mask was presented again for 100 ms; and (i) a blank screen appeared for 1600 ms while the participant named the green target word.

The response latency to name the target (i.e., the green word) aloud was recorded, and the experimenter recorded any errors made by the participant. An error occurred if the participant gave no response or gave an incorrect response. Trials for

Table 1. Participant Characteristics by Age Group.

	Younger	Middle-aged	Older	Correlations with age
Age range	20 – 39	40 – 59	60 – 90	
N	84 (35 males)	86 (29 males)	131 (56 males)	
Age	29.39 (6.32)	49.20 (5.59)	72.23 (6.96)	
Education	5.48 (.94)	5.52 (1.19)	5.79 (1.04)	.12
Vocabulary	31.29 (5.29)	32.66 (6.68)	34.80 (4.24)	.26
Health rating	3.45 (.55)	3.34 (.68)	3.22 (.72)	–.15
Medications	0.38 (.79)	1.24 (2.39)	1.84 (1.94)	.30

Note. Means with standard deviations in parentheses. Health rating is a self-reported measure on a scale of 1 (poor) to 4 (excellent). The mean education level corresponds to some college education (5 = some college, 6 = college graduate). All correlations were significant at $p < .05$.

Table 2. Summary of Negative Priming for Words Trials.

	Prime screen	Probe screen
Control	**BAG** *CAT*	*GIN* **TIE**
Ignored repetition	**BAG** *CAT*	**CAT** *TIE*
No distractor	**BAG** *CAT*	**GIN**

Note. The word in bold letters is the target (i.e., green word) and the word in italics is the distractor (i.e., red word).

which the response was not registered by the computer or in which the participant made irrelevant noises were also considered to be error trials.

Stroop Task

In the Stroop Color and Word Test, participants were given a page containing five columns of 20 blocks of color. The color blocks consisted of *xxxx* printed in red, green, or blue ink. The red, blue, and green colors were randomly distributed. Participants were asked to name the colors, and they were given 45 s for this task. If a participant made an error, he or she corrected the error and continued reading. Then, participants were presented with a page containing five columns of 20 words in different colored ink. The words *red, green,* and *blue* were printed in red, green, or blue ink. Each color word was presented in an incompatible colored ink. Again participants received 45 s to name the color of the ink blocks. If a participant made an error, he or she corrected the error and continued reading. The number of items read during the allotted time was recorded.

Reading Distraction

Seven of the stories from Connelly et al. (1991) were used in this task. There were two types of stories. Three control stories contained 125 words. Three experimental stories were similar except that, in addition to the 125 words relevant to the story, they contained words and phrases that were irrelevant, but related, to the story. These irrelevant words and phrases were interspersed randomly throughout the text and were printed in italics. Participants were instructed to ignore the italicized text when reading the experimental stories aloud. Immediately after reading each story, participants answered four multiple choice comprehension questions about the story. Each question had three answers from which to choose. One control story was read for practice. The participants then read aloud an experimental story followed by a control story until all six stories had been read. The reading time for each story was recorded.

Free Recall Task

In the Free Recall task, there were two lists of 25 words, each containing five words from five categories. Each word was presented for 5 s by a slide projector. Participants were instructed to learn the words for later recall. After all 25 words had been presented, participants were given unlimited time to write down the words from the list. The procedure was then repeated with the second list of words. The number of times that a participant wrote down items that were not on the list was recorded as the number of intrusions.

Working Memory

The two measures of working memory were similar to those used by Salthouse and Babcock (1991). In the Reading Span task, participants read aloud a series of sentences. After each sentence, they answered a very simple question about the sentence while simultaneously trying to remember the last word from each sentence. The series of sentences ranged in size from 1 to 7 sentences, and there were three sets at each level. The task was stopped when a participant made three consecutive errors. The score was the number of trials on which the participant correctly answered the questions and recalled the words.

In the Computation Span task, participants saw a series of arithmetic problems. After each problem, they solved the problem while simultaneously remembering the last digit from the problem. The series of problems ranged in size from 1 to 7 problems, with three sets at each level. The task was stopped when a participant made three consecutive errors. The score was the number of trials on which the participant correctly solved the problems and remembered the digits.

Perceptual Speed
The three measures of perceptual speed were the WAIS Digit Symbol Substitution task (Wechsler, 1981), the Letter Comparison task (Salthouse & Babcock, 1991), and the Pattern Comparison task (Salthouse & Babcock, 1991). In the Letter Comparison task, participants decided if pairs of letter strings, each of which consisted of 3, 6, or 9 letters, were the same or different. They wrote an *S* on the line between them if they were the same, and a *D* if they were different. There were three 30-s sections, one at each level (3, 6, or 9 letters), each containing 32 pairs. The score was the sum of the number correctly completed on each section. The Pattern Comparison task was identical to the Letter Comparison task except that participants compared pairs of line drawings composed of 3, 6, or 9 line segments.

Task Order
Participants came into the laboratory on 3 days during the same week. A total of 23 tasks was administered in the same order for each participant. Only those tasks used in the current study have been presented here. The Reading Distraction, and the Computation Span tasks were presented on Day 1. The Negative Priming for Words, the Stroop, the Reading Span, the Digit Symbol Substitution, and the Letter Comparison tasks were presented on Day 2. The Free Recall and the Pattern Comparison tasks were presented on Day 3.

RESULTS

Reliabilities

Reliability estimates were computed for the measures and are shown in Table 3. The reliabilities of the Negative Priming for Words task conditions were computed by correlating performance on the odd and even number trials and correcting this correlation by the Spearman-Brown formula. Test-retest reliabilities for the Stroop conditions were computed by Golden (1978). Estimates of the reliabilities of the Reading Distraction conditions were computed by correlating performance on the different stories and correcting this correlation by the Spearman-Brown formula. Free recall task reliability was estimated by correlating performance on the two recall lists and correcting this correlation using the Spearman-Brown formula. A test-retest reliability estimate was calculated for the Digit Symbol test by Wechsler (1981). Finally, reliability estimates for the Letter and Pattern Comparison tasks and for the working memory measures were calculated by Salthouse and Babcock (1991).

Negative Priming for Words Task

The data from one younger adult and four older adults were lost due to equipment failures, and one younger adult was eliminated due to incorrect responses on more than 50% of the trials. Individual means were trimmed to 2.5 standard deviations within each trial type. An average of 0.67 trials per condition were eliminated for the younger adults (*SD* = .35) and middle-aged adults (*SD* = .38), and an average of 0.63 trials (*SD* = .38) per condition were eliminated for the older adults. Data from four younger adults, two middle-aged adults, and four older adults were not used because the mean response latencies were greater than 2.5 standard deviations from the age group mean in at least one condition. These very long response latencies were probably due to failure to adequately adjust the voice-activated relay system for these participants.

Table 3. Reliability Estimates.

Negative Priming for Words	
Control	.96
Ignored repetition	.95
No distractor	.97
Stroop	
Colors	.86
Interference	.82
Reading Distraction	
Control	.88
Interference	.92
Free recall	.85
Working memory	
Reading Span	.86
Computation Span	.90
Perceptual Speed	
Digit Symbol Substitution	.82
Letter Comparison	.94
Pattern Comparison	.94

The analyses were thus conducted using data from 78 younger adults, 84 middle-aged adults, and 123 older adults. The means for each trial type are presented in Table 4.

Inhibition Analyses

Inhibition was operationalized as the difference in response latency on control trials and ignored repetition trials. The differences in response latencies for these trial types for each age group are shown in Table 4. A 3 (Age Group) × 2 (Trial Type) analysis of variance was conducted. Participants were significantly slower to respond on ignored repetition trials than on control trials, $F(1, 282) = 125.23$, $MSE = 214.33$, $p < .001$. There was also a significant main effect of age group, $F(2, 282) = 10.55$, $MSE = 7018.54$, $p < .001$. There was, however, also a significant interaction of age and trial type, $F(2, 282) = 3.28$, $MSE = 214.33$, $p = .039$. Further analysis of this interaction revealed a larger effect of trial type for younger than for older adults, $F(1, 199) = 7.00$, $p = .009$, with the middle-aged group not significantly different from either the younger or the older group. Comparisons were then conducted within each age group. Significant negative priming was shown by the younger, $F(1, 77) = 101.27$, $MSE = 129.77$, $p < .001$, middle-aged, $F(1, 83) = 27.67$, $MSE = 252.97$, $p < .001$, and older adults, $F(1, 122) = 29.33$, $MSE = 241.41$, $p < .001$. Although significant negative priming was obtained for all age groups, the performance of older adults was not hindered as much as that of younger adults by the presentation of a target word that was previously a distractor word. In other words, there was less inhibition by the older adults.

An analysis was also conducted in order to examine the errors that participants made. A trial was scored as an error for this analysis if the participant gave no answer or gave an incorrect answer. Trials in which the equipment malfunctioned were not included in the error category. The means for each condition are presented in Table 4.

A 3 (Age Group) × 2 (Trial Type) analysis of variance revealed that participants made significantly more errors on ignored repetition trials than on control trials, $F(1, 282) = 10.64$, $MSE = 1.06$, $p < .001$. There was a significant main effect of age, $F(2, 282) = 20.48$, $MSE = 5.99$, $p < .001$, but there was no significant interaction, $F(2, 282) = 1.39$, $MSE = 1.06$, $p = .250$.

Interference Analyses

Interference was operationalized as the difference in response latency between control trials and no distractor trials. The difference scores are shown in Table 4. A 3 (Age Group) × 2 (Trial Type) analysis of variance was conducted.

Table 4. Performance by Age Group on Negative Priming for Words Task Trials.

	Younger	Middle-aged	Older
Response latency			
Control	624 (60)	656 (61)	666 (59)
Ignored repetition	642 (60)	669 (58)	677 (62)
Inhibition	18	13	11
No distractor	577 (59)	610 (62)	619 (56)
Interference	46	46	48
Errors			
Control	.38 (.67)	.67 (.99)	1.69 (2.47)
Ignored repetition	.55 (.85)	.88 (1.26)	2.17 (2.78)
Inhibition	.17	.21	.48
No distractor	.15 (.40)	.29 (.67)	1.07 (1.62)
Interference	.23	.38	.62

Note. Means with standard deviations in parentheses. The inhibition score was derived by subtracting the control trial mean from the ignored repetition trial mean. The interference score was derived by subtracting performance on the no distractor trials from performance on the control trials.

Participants were significantly slower on control trials than on no distractor trials, $F(1, 282) = 1031.77$, $MSE = 288.30$, $p < .001$. There was also a significant main effect of age, $F(2, 282) = 12.85$, $MSE = 6731.48$, $p < .001$, but there was no significant interaction, $F(2, 282) < 1$.

Analyses of variance for errors also revealed a significant effect of trial type, $F(1, 282) = 24.27$, $MSE = 0.95$, $p < .001$, and of age, $F(2,282) = 21.33$, $MSE = 3.40$, $p < .001$, but no significant interaction, $F(2, 282) = 2.00$, $MSE = 0.95$, $p = .137$.

Stroop Interference Task

Eight older adults were excluded from this analysis due to failure to follow instructions. Therefore, there were 84 young, 86 middle-aged, and 123 older participants in this analysis. The mean performances in each condition by each age group are presented in Table 5. The Stroop ratio was computed by subtracting the number read in the interference condition from the number read in the color block condition and dividing this difference by the number read in the color block condition. An ANOVA revealed a significant effect of age on susceptibility to interference, $F(2, 290) = 6.59$, $MSE = .01$, $p < .01$. Post hoc Tukey HSD tests demonstrated that both middle-aged and older adults were more susceptible to interference than were the younger adults.

Reading Distraction Task

Two younger adults, three middle-aged adults, and five older adults did not complete this task correctly and thus were excluded from these analyses. Therefore, there were 82 young, 83 middle-aged, and 126 older participants in this analysis. The average performance of participants is presented in Table 5. Participants were significantly slower to read the stories contain-

Table 5. Performance on Tasks by Age Group.

	Younger	Middle-aged	Older
Stroop task			
Colors	76.43 (9.78)	72.88 (11.86)	63.67 (12.52)
Interference	44.74 (9.45)	39.38 (10.11)	34.02 (8.78)
Ratio	.41 (.11)	.46 (.10)	.47 (.10)
Reading Distraction			
Control	136.73 (35.25)	138.56 (2.13)	153.17 (25.68)
Interference	300.01 (133.85)	327.57 (159.04)	404.26 (150.20)
Difference	163.28	189.01	251.09
Control comprehension	10.00 (1.47)	9.74 (1.29)	9.41 (1.40)
Interference comprehension	8.52 (1.75)	7.90 (2.13)	7.21 (1.95)
Difference	1.48	1.84	2.20
Free Recall Intrusions	1.80 (2.16)	2.07 (3.12)	2.63 (3.91)
Pattern Comparison	62.78 (8.26)	55.15 (10.38)	44.62 (11.25)
Letter Comparison	43.14 (6.88)	36.51 (7.75)	30.79 (5.88)
Digit Symbol	65.72 (11.35)	56.39 (13.48)	45.47 (11.98)
Computation Span	9.15 (3.55)	7.51 (2.75)	6.50 (3.15)
Reading Span	8.49 (2.93)	7.38 (2.79)	6.40 (2.67)

Note. Means with standard deviations in parentheses. The Stroop ratio was calculated by dividing the difference between the color block and the interference trials by the number completed on the color block trial. The Reading Distraction score was computed by subtracting the control story reading time from the experimental story reading time.

ing extra information than to read the control stories, $F(1, 288) = 632.55$, $MSE = 8942.81$, $p < .001$. Older adults were significantly slower than the younger adults, $F(2, 288) = 15.05$, $MSE = 13904.82$, $p < .001$, and there was also a significant interaction, $F(2, 288) = 11.96$, $MSE = 8942.81$, $p < .001$. There was a larger interference effect for older than for both younger, $F(1, 206) = 22.45$, $p < .001$, and middle-aged groups, $F(1, 207) = 9.58$, $p = .002$.

An analysis of reading comprehension was also conducted. Participants correctly answered significantly more questions from the control stories than from the stories containing extra information, $F(1, 288) = 233.92$, $MSE = 2.03$, $p < .001$. There was a significant main effect of age, $F(2, 288) = 12.42$, $MSE = 3.72$, $p < .001$, and there was also a significant interaction, $F(2, 288) = 3.31$, $MSE = 2.03$, $p = .038$. The significant interaction was due to a larger interference effect for older than for younger adults, $F(1, 206) = 6.54$, $p = .001$.

Free Recall Intrusion Task

An analysis of variance revealed no significant effect of age on the number of intrusions made during the free recall task, $F(2, 298) = 1.83$, $MSE = 10.74$, $p = .163$. This is probably due to the low number of intrusions in this task. The mean level of performance for each age group is shown in Table 5.

Correlations

Correlations were computed in order to examine the relations among the measures of inhibition, interference, age, speed, and working memory. A composite working memory score was computed by averaging the z scores of the Reading Span and Computation Span tasks. A composite perceptual speed score was computed by taking the average of the z scores for the Letter Comparison, Pattern Comparison, and Digit Symbol tasks. The mean level of performance of each of the working memory and speed measures is presented in Table 5. The correlation matrix is in Table 6.

The correlation of age with the Negative Priming for Words task was significant, again demonstrating less negative priming for older than for younger adults. The pattern of relations among age and the interference measures demonstrated an increase in interference with increased age. The only measure for which this relation was not demonstrated was for interference in the Negative Priming for Words task. For the Negative Priming for Words task, there was a significant negative correlation between inhibition and interference.

The patterns of relations among inhibition and interference and speed and working memory were also examined. Slower speed was associated with less inhibition. No significant relation was found, however, between inhibition and

Table 6. Correlation Matrix.

	1	2	3	4	5	6	7	8
1. Age	–							
2. Inhibit Word	–.14	–						
3. Interfere Word	.03	–.14	–					
4. Stroop ratio	.20	.04	.07	–				
5. Reading Distraction	.32	–.03	.01	.20	–			
6. Free Intrusions	.10	–.10	.02	.09	.19	–		
7. Working memory	–.39	–.02	–.05	–.32	–.39	–.10	–	
8. Speed	–.71	.14	.02	–.29	–.59	–.09	.48	–

Note. Correlations are presented for the 266 participants with complete data. All correlations greater than .11 are significant at $p < .05$. The inhibition measure was computed by subtracting the control trial mean from the ignored repetition trial mean. The interference score for the Word task was derived by subtracting performance on the no distractor trials from performance on the control trials. The Stroop ratio was calculated by dividing the difference between conditions (i.e., between the color block and the interference block) by the number completed on the color block trial. The Reading Distraction score was computed by subtracting the control story reading time from the experimental story reading time.

working memory. For the Stroop and Reading Distraction measures, lower susceptibility to interference was associated with larger working memory spans and with faster speed.

Hierarchical Regression Analyses

It was predicted that age differences in perceptual speed would mediate age differences in inhibition and interference. Thus hierarchical regression analyses were conducted in which age differences in the inhibition and interference measures were examined before and after the control of perceptual speed. It was assumed that if the age-related variance in inhibition and interference was greatly reduced after the control of perceptual speed, then perceptual speed is important to the age-inhibition and age-interference relations. These analyses are summarized in Table 7.

Only those inhibition and interference measures that were related to age in the correlational analyses were included in the hierarchical regression analyses. The age-related variance in the measures of inhibition and interference was small. After the control of perceptual speed, the age-related variance in all of the measures was greatly reduced. Eighty one to 100% of the age-related variance in inhibition and interference was found to be related to perceptual speed. After the control of perceptual speed, there was no significant remaining age-related variance in Negative Priming for Words or in the Stroop task. There was still a small, but significant, proportion of age-related variance in Reading Distraction that was independent of perceptual speed.

It was also hypothesized that age differences in inhibition and interference would be related to age differences in working memory. Hierarchical regression techniques were used in order to test this hypothesis. Only those measures that were significantly correlated with working memory were included in these analyses. The Word task inhibition and interference measures did not significantly correlate with working memory, and were, therefore, not considered to be potential mediators of the age-related variance in working memory. The results of these analyses are summarized in Table 8. The age-related variance in working memory was reduced by less than 50% by the control of Stroop Interference or Reading Distraction. Significant age-related variance in working memory remained after the control of each of these measures.

Table 7. Hierarchical Regression Analyses.

	R^2	Change	F	p	% Variance
Word task inhibition					
Age	.019		5.08	.025	
Speed	.019		4.97	.027	
Age	.022	.003	< 1		84%
Stroop ratio					
Age	.039		10.58	.001	
Speed	.085		24.45	< .001	
Age	.085	.000	< 1		100%
Reading Distraction difference score					
Age	.102		30.00	< .001	
Speed	.345		138.76	< .001	
Age	.364	.019	8.02	.005	81%

Note. The hierarchical regression analyses were conducted using the 266 participants with complete data. % variance was computed by taking the difference between the original age-related variance and the age-related variance after the statistical control of the potential mediator and dividing this difference by the original age-related variance.

Table 8. Hierarchical Regression Analyses with Working Memory as the Dependent Variable.

	R^2	Change	F	p	% Variance
Working memory					
Age	.150		46.38	< .001	
Stroop ratio	.103		30.29	< .001	
Age	.212	.109	36.34	< .001	27
Reading Distraction	.151		47.07	< .001	
Age	.228	.077	26.10	< .001	49

Note. The hierarchical regression analyses were conducted using the 266 participants with complete data. % variance was computed by taking the difference between the original age-related variance and the age-related variance after the statistical control of the potential mediator and dividing this difference by the original age-related variance.

DISCUSSION

One major purpose of the present study was to evaluate whether or not older adults can inhibit irrelevant information and prevent this information from interfering with working memory. As in previous studies of age differences in negative priming (e.g., Hasher et al., 1991; Kane et al., 1994), we found larger negative priming for younger than for older adults. In contrast to previous studies that found no significant negative priming in older adults, we did find significant negative priming for participants of all ages. Thus although older adults seem less able than younger adults to successfully inhibit information, older adults were shown to be capable of inhibition.

Although the procedure was very similar to that used by Kane et al. (1994), we obtained larger negative priming effects for older adults than did Kane et al. (1994). The only major difference between the Kane et al. procedure and that used in the present study was the presence, in the Kane et al. study, of two extra conditions, and thus 72 extra trials. The extra conditions involved one in which the same distractor was used on the prime and probe trials, and one in which the target on the prime trial became the distractor on the probe trial. Perhaps the greater length of the Kane et al. study contributed to the lack of inhibition in the older adults. More likely, the differential results were found because we used a much larger sample of participants, therefore increasing our power to detect an effect of condition.

Negative priming in older adults has been found in other studies when priming of location rather than of target identity is utilized (e.g., Connelly & Hasher, 1993). A few studies have reported significant negative priming in older adults using target identity tasks (e.g., Kramer et al., 1994; Sullivan, Faust, & Balota, 1995). Although Sullivan and Faust (1993) found significant negative priming in older adults, May et al. (1995) suggest that this result was due to the inclusion of repeated target trials (i.e., trials in which the target is the same on the prime and probe trials) that led to episodic retrieval of the prime trial during the probe trial. Thus they suggest that inhibition was not the primary determinant of negative priming in the Sullivan and Faust (1993) study.

In a review of the negative priming literature, May et al. (1995) note that older adults have been found to show negative priming when identification of the target is difficult, when repeated target trials are included (because then episodic retrieval of the probe trial is useful to the participant), and when yes/no lexical decision tasks are used. Our study used none of these conditions, however, and we obtained negative priming for older adults for identity information. In our study, a naming task was used, the words were presented for 300 ms (the same as in Kane et al., 1994, Experiment 1), and there were no trials in which the target on the probe trial was the same as the target on the prime trial, so episodic retrieval was never beneficial to the participant. We believe, therefore, that older adults can inhibit identity information, although their inhibitory systems do not function as well as those of younger adults.

Another important purpose of the present study was to look at the relations between inhibition and several other possible contributors to age differences in working memory performance. First, an age-related increase in susceptibility to interference from distracting information was suggested to be related to age differences in inhibition. Susceptibility to interference does appear to increase with increased age. In both the Stroop and the Reading Distraction Interference tasks, older adults were more distracted by irrelevant information than were the younger adults. We did not, however, find an effect of age on interference in the Word task, replicating Stoltzfus et al. (1993). The negative priming for words task was not a very demanding selection task and this may be why age differences in interference were not found when using this task.

There was a small but significant negative relation between inhibition and interference in the Word task. As predicted, participants who had less efficient inhibitory function suffered from larger effects of interference. There was, however, no significant relation between inhibition and interference as measured by the Stroop, Reading Distraction, and Intrusions tasks. Because there were no age differences in the selective attention interference measure and because there was no relation between inhibition and any of the other interference measures, the results of this study did not support the hypothesis that the age-related increase in susceptibility to interference is due in part to inhibitory deficiencies.

As hypothesized, perceptual speed was found to be important to the age differences in inhibition and interference. The age-related variance in the inhibition measure was reduced by 84% by the control of perceptual speed, and the age-related variance in the interference measures was reduced by between 81% and 100% by the control of perceptual speed. Thus as was found by Salthouse and Meinz (1995), age differences in inhibition and interference were associated with age differences in perceptual speed. We found evidence, therefore, that two consequences of the slower and less efficient processing system possessed by older adults are an impaired ability to inhibit previously relevant information and an increase in susceptibility to interference.

The final purpose of this study was to examine a possible link between age differences in inhibition and interference and age differences in working memory. One hypothesis is that an increase in susceptibility to interference from distractors would result in a less efficient use of working memory. If irrelevant information gets into working memory, there would be less capacity for the relevant information. Also, decreased efficiency of inhibitory processes would prevent the suppression of irrelevant information, thus maintaining this information in working memory. No support was found for the hypothesis that age differences in working memory are related to age differences in inhibition. The inhibition measure was not significantly related to working memory. Age differences in interference, however, were related to age differences in working memory. The age-related variance in working memory was reduced by the control of Stroop and Reading Distraction performance, although in each case, over half of the age-related variance in working memory was not associated with interference. Thus an increase in susceptibility to interference may contribute to age differences in working memory, but there are certainly other factors as well.

Future research should focus on finding better measures of inhibitory functioning. The negative priming measure used in this study produced priming effects that were so small (between 10 and 20 ms) that there was little chance for this measure of inhibition to be statistically significantly associated with the measures of working memory. Older adults were found to use inhibitory mechanisms as measured by negative priming. However, increased age was associated with less efficient inhibitory function, and was also associated with increased susceptibility to interference from irrelevant information. The age differences in both inhibition and interference were found to be related to decreases in processing speed with increased age. Age differences in interference, but not inhibition, were found to be related to age differences in working memory.

REFERENCES

Cohen, G. (1988). Age differences in memory for texts: Production deficiency or processing limitations? In L. Light & D. Burke (Eds.), *Language, memory, and aging* (pp. 171-190). Cambridge: Cambridge University Press.

Connelly, S. L., & Hasher, L. (1993). Aging and inhibition of spatial location. *Journal of Experimental Psychology: Human Perception and Performance, 19,* 1238-1250.

Connelly, S. L., Hasher, L., & Zacks, R. T. (1991). Age and reading: The impact of distraction. *Psychology and Aging, 6,* 533-541.

Dulaney, C. L., & Rogers, W. A. (1994). Mechanisms underlying reduction in Stroop interference with practice for young and old adults. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* 470-484.

Engle, R. W., Conway, A. R. A., Tuholski, S. W., & Shisler, R. J. (1995). A resource account of inhibition. *Psychological Science, 6,* 122-125.

Golden, C. J. (1978). *Stroop color and word test.* Wood Date, IL: Stoeley Company.

Hasher, L., Stoltzfus, E. R., Zacks, R. T., & Rypma, B. (1991). Age and inhibition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 163-169.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. Bower (Ed.), *The psychology of learning and motivation* (Vol. 22) (pp. 193-225). New York: Academic Press.

Kane, M. J., Hasher, L., Stoltzfus, E. R., Zacks, R. T., & Connelly, S. L. (1994). Inhibitory attentional mechanisms and aging. *Psychology and Aging, 9,* 103-112.

Kramer, A. F., Humphrey, D. G., Larish, J. F., Logan, G. D., & Strayer, D. L. (1994). Aging and inhibition: Beyond a unitary view of inhibitory processing in attention. *Psychology and Aging, 9,* 491-512.

May, C. P., Kane, M. J., & Hasher, L. (1995). Determinants of negative priming. *Psychological Bulletin, 118,* 35-54.

McDowd, J. M., & Oseas-Kreger, D. M. (1991). Aging, inhibitory processes, and negative priming. *Journal of Gerontology, 46,* 340-345.

Neumann, E., & Deschepper, B. G. (1992). An inhibition-based fan effect: Evidence for an active suppression mechanism for selective attention. *Canadian Journal of Psychology, 46,* 1-40.

Park, D. C., Smith, A. D., Lautenschlager, G., Earles, J., Frieske, D., Zwahr, M., & Gaines, C. (in press). Mediators of long term memory performance across the life span. *Psychology and Aging.*

Salthouse, T. A. (1992). Influence of processing speed on adult age differences in working memory. *Acta Psychologica, 79,* 155-170.

Salthouse, T. A. (1994). The nature of the influence of speed on adult age differences in cognition. *Developmental Psychology, 30,* 240-259.

Salthouse, T. A., & Babcock, R. L. (1991). Decomposing adult age differences in working memory. *Developmental Psychology, 27,* 763-776.

Salthouse, T. A., & Meinz, E. J. (1995). Aging, inhibition, working memory, and speed. *Journal of Gerontology: Psychological Sciences, 50B,* P297-P306.

Stoltzfus, E. R., Hasher, L., Zacks, R. T., Ulivi, M., & Goldstein, D. (1993). Investigations of inhibition and interference in younger and older adults. *Journal of Gerontology, 48,* 179-188.

Storandt, M. (1977). Age, ability level, and method of administering and scoring the WAIS. *Journal of Gerontology, 32,* 175-178.

Sullivan, M. P., & Faust, M. E. (1993). Evidence for identity inhibition during selective attention in old adults. *Psychology and Aging, 8,* 589-598.

Sullivan, M. P., Faust, M. E., & Balota, D. (1995). Identity negative priming in old adults and individuals with dementia of the Alzheimer's type. *Neuropsychology, 9,* 537-555.

Tipper, S. P. (1985). The negative priming effect: Inhibitory priming by ignored objects. *The Quarterly Journal of Experimental Psychology, 37A,* 571-590.

Tipper, S. P. (1991). Less attentional selectivity as a result of declining inhibition in older adults. *Bulletin of the Psychonomic Society, 29,* 45-47.

Wechsler, D. (1981). *Manual for the Wechsler Adult Intelligence Scale-Revised.* New York: The Psychological Corporation.