Journal of Experimental Psychology:
Learning, Memory, and Cognition
1991, Vol. 17, No. 1, 163-169

Age and Inhibition

Lynn Hasher and Ellen R. Stoltzfus
Duke University

Rose T. Zacks
Michigan State University

Bart Rypma
Duke University

Two experiments assess adult age differences in the extent of inhibition or negative priming generated in a selective-attention task. Younger adults consistently demonstrated negative priming effects; they were slower to name a letter on a current trial that had served as a distractor on the previous trial relative to one that had not occurred on the previous trial. Whether or not inhibition dissipated when the response to stimulus interval was lengthened from 500 ms in Experiment 1 to 1,200 ms in Experiment 2 depended upon whether young subjects were aware of the patterns across trial types. Older adults did not show inhibition at either interval. The age effects are interpreted within the Hasher-Zacks (1988) framework, which proposes inhibition as a central mechanism determining the contents of working memory and consequently influencing a wide array of cognitive functions.

There are many findings in the cognitive gerontology literature that are consistent with the suggestion that older adults are more likely to be distracted by both environmental events and internal thoughts than are younger adults (see Layton, 1975). Such evidence can be found across cognitive domains ranging from visual selective attention (e.g., Madden, 1983) to memory (e.g., Mueller, Kausler, Faherty, & Oliveri, 1980; Winthorpe & Rabbitt, 1988) to language production (e.g., Gold, Andres, Arbuckle, & Schwartzman, 1988; Obler, 1980).

One critical question concerns the mechanisms that underlie presumed increases in distractibility with age. Recent theoretical and empirical developments in the understanding of selective attention may provide insight into the basis for these behaviors. In particular, one line of work in selective attention has converged on the notion that the process of selecting a target stimulus may entail, in addition to any excitation associated with the target, a suppression or inhibition process that operates on response tendencies toward unselected stimuli (see, e.g., Keele & Neill, 1978; Lowe, 1985; Neill, 1977, 1979; Neumann & DeSchepper, 1989a; Tipper, 1985; Tipper & Cranston, 1985). The presence of inhibition incurred during selection on one trial may be seen when a previously unselected distractor becomes the target on the subsequent trial. Young adults are reliably slowed (as measured, e.g., by the time to name the target) when distractors become targets relative to when a current target was not the previous trial's distractor. Carryover or suppression effects of this sort (sometimes called *negative priming*) have been reported for a broad range of stimuli, including letters (Tipper & Cranston, 1985), pictures (Tipper, 1985), pictures and words (Tipper & Driver, 1988), and Stroop items (Lowe, 1985).

It is possible that the mechanism underlying heightened distractibility for older adults is a reduction in the effectiveness of the inhibitory mechanisms that otherwise operate to facilitate, if not to permit, selective attention. We report two experiments whose findings are consistent with the assumption of an age-related decline in inhibitory efficiency. As well, we report data on the time course of dissipation—or lack thereof—of suppression effects for young adults. In the discussion, we relate the developmental finding to a theory (Hasher & Zacks, 1988) in which inhibitory attentional mechanisms play a central role in memory and language.

Experiment 1

To compare the ability of younger and older adults to suppress irrelevant information in the context of a selection procedure, we used a letter-naming task introduced by Tipper and Cranston (1985, Experiment 2). Subjects were asked to name one of two letters (on the basis of color) on each of a series of trials. Half of the trials were termed *sequential* because the previous trial's irrelevant letter served as the current trial's target. The remaining trials served as controls on which both the target and distractor were different from those on the previous trial. We expected to see a greater carryover effect on sequential trials for younger adults than for older adults; older adults were not expected to efficiently suppress the irrelevant letter on a given trial and therefore would not be slowed to name it when it became the target letter on the next trial.

This research was supported by a Biomedical Research Support Grant from Duke University and by National Institutes on Aging Grant AGO 4306 to Lynn Hasher and Rose T. Zacks. Initial work on this project formed a portion of Bart Rypma's master's thesis. The data were presented at the annual meeting of the Psychonomic Society, Atlanta, GA, November, 1989.

We greatly appreciate the assistance of Mauri Smith, Monica Oliver, Anastasia Danos, John Jost, Ron Collis, and Caroline Roe at various stages of the project. Helpful comments were provided by several colleagues, including Reed Hunt, Marilyn Hartman, Robert Weisberg, Marc Marschark, Ewald Neumann, and two anonymous reviewers.

Correspondence concerning this article should be addressed to Lynn Hasher, Department of Psychology, Duke University, Durham, North Carolina 27706.

Method

Design and subjects. The performance of younger and older subjects was compared on a task in which two letters—a target in one color (e.g., red) and a distractor in another color (e.g., green)—appeared on a screen. One color served to identify the target letter on all trials. There were two letter-naming conditions: a sequential one in which the current target letter had been the previous pair's distractor letter, and a control condition in which both the current target letter and its distractor were different from both members of the previous pair.

Thirty younger (range = 18–24 years, M = 19.4 years) and 30 older (range = 62–74 years, M = 67.9 years) adults participated. The young adults were students and were either enrolled in an introductory psychology course or were recruited from the undergraduate population at large. Those in the course received credit toward a requirement, and the others were paid $5 for their participation. The older adults were recruited from the subject pool maintained by the Duke University Center for the Study of Aging and Human Development. These participants were paid $10 plus parking, the local standard rate for experiments of approximately an hour's duration.

Materials. Twelve letters served as experimental stimuli (A, B, C, D, E, J, K, N, O, S, T, and V). The letters were presented in pairs in the middle of a Mitsubishi color monitor, which was controlled by a program executed on an AT-compatible microcomputer with an enhanced graphics adapter (EGA) card. Each letter was 6 mm in height and width. A single 6-mm space separated the two letters. Subjects sat approximately 75 cm from the screen. For the two-letter stimulus array, the visual angle subtended by the distance from the extreme outer edge of one letter to the outer edge of the other was 1.37°.

Stimuli were presented in lists of 10 letter pairs. There were 12 unique sequential lists and 12 unique control lists. On Trials 3 to 9 of the sequential lists, the target was always the distractor of the previous trial. (The sequence from Pair 1 to Pair 2 and from Pair 9 to Pair 10 was randomly determined in order to decrease the chances of subjects noticing the sequential pattern in the critical lists.) Target letters were randomly assigned to the right- or left-hand position with the constraint that targets could not occur in the same position more than three times in succession.

Control lists were constructed so that the target letter and target position in each of the 12 lists matched the target letter and target position in each of the sequential lists. The distractor letter for each control trial was then chosen randomly from the 11 remaining letters with the constraint that no distractor letter appear as a target or distractor letter on the subsequent trial.[1]

Each of the 12 sequential lists and each of the 12 control lists appeared twice in the experimental session, once in the first half of the experiment and once in the second half, for a total of 48 list presentations. The order of presentation of lists was determined randomly for each of the halves of the experiment, with the restriction that no list type could occur more than three times in succession.

Procedure. Subjects were tested individually. One-half of the subjects in each age group was instructed to name the red letter, and the other half was instructed to name the green letter.[2] Instructions encouraged subjects to place equal emphasis on speed and accuracy.

The experiment began with a familiarization procedure in which subjects first saw each stimulus letter on the screen. They then saw the sequence of events within a single trial and practiced using the voice-activated relay, which was used to record the onset of a response to a letter pair. During the familiarization procedures, the sensitivity of the relay was adjusted to each participant's voice, using a counting task. Subjects then received five full practice lists of 10 control trials each. Only control lists were used in this phase of the experiment to diminish the opportunity for participants to become aware of the structure of the sequential lists. As will be seen in Expriment 2, this concern was more important than initially anticipated.

In the experiment proper, each list began with an instruction to the participant to press the keyboard's space bar. A trial then consisted of the following sequence of events: White fixation crosses appeared for 500 ms at the points at which the red and green letters would next appear. The letters were then presented for 200 ms and were immediately replaced by a pair of asterisks, each in the color of the letter it had replaced. The asterisks remained on the screen until the subject initiated a response, which then reinstated the fixation crosses for the next trial. Reaction times were measured from the offset of the array to the onset of the response. They were recorded on all trials, but only responses on Pairs 3 to 9 were entered into the analysis of the data.[3] With 24 lists of each type, a maximum of 168 responses was scored for each condition.

If the subject missed a letter display, he or she said "go" to start the next trial, as instructed during the familiarization procedure. Subjects were formally offered a break after 24 lists, although because all trials were self-initiated they were able to take breaks at their own convenience. No records were kept of these pauses.

Immediately after the experiment proper, subjects were asked a series of questions about their perceptions of the nature of the lists of letter pairs. In particular, our goals were twofold. First, we were interested in the degree to which subjects became aware of the sequential nature of some of the lists. To this end, subjects were asked whether they noticed any patterns in the lists. Subjects who said yes were then asked to specify those patterns and, if they did so correctly, were classified as being aware of the sequential manipulation. The data of these subjects were deleted, leaving 25 younger subjects and 28 older subjects whose data constituted the set analyzed for the main experiment.[4]

We were also interested in the emphasis subjects placed on speed versus accuracy. To this end, subjects were asked to assign a ratio value to represent their relative emphasis on these two task demands (e.g., 60% emphasis on accuracy). Following this procedure, subjects were given the Shipley-Hartford vocabulary test and were debriefed.

Results and Discussion

Subject comparisons. The mean ages of the 25 younger and 28 older unaware subjects were 19.4 and 68.1, respectively. These groups of subjects did not differ in years of education (14.0 and 15.0, respectively), $t(51) = 1.75$, $p < .09$, in number correct on the Shipley-Hartford vocabulary test

[1] An error in programming resulted in rare occurrences of the reappearance of a previous distracting letter as a target on a subsequent trial in the control condition. Across subjects, this occurred on fewer than 2% of control trials. This error might be expected to reduce differences between sequential and control trials. A rescoring of protocols omitting these trials did not alter any conclusions.

[2] Although no test for color blindness was given, only 1 subject reported any difficulty with determining the appropriate color. That subject received additional practice trials and produced error rates in the main task that were acceptable. One older subject was replaced for failing to follow instructions. The data from 3 other subjects were replaced because of equipment problems.

[3] Tipper and Cranston (1985, Experiment 2) used data from odd-numbered trials only.

[4] A similar procedure was followed in the second experiment, at which time we became aware ourselves of the impact of this difference between subjects, a matter discussed at the end of Experiment 2.

Table 1
Mean Reaction Times and Proportions of Errors (in parentheses) for Sequential and Control Trials for Younger and Older, Unaware Adults for Experiments 1 and 2

	Experiment 1 (RSI = 500 ms)				Experiment 2 (RSI = 1,200 ms)			
Group	*n*	Sequential	Control	Inhibition	*n*	Sequential	Control	Inhibition
Younger	25	284.4 (.056)	275.5 (.034)	8.9	21	298.8 (.033)	291.2 (.022)	7.5
Older	28	337.5 (.075)	335.1 (.061)	2.4	28	365.3 (.066)	367.1 (.059)	−1.8

Note. RSI = response-to-stimulus onset interval.

(scores of 34.5 and 34.0 of 40 possible, respectively), $t(51) < 1$, or in the relative emphasis placed on accuracy (57.1% and 64.8%, respectively), $t(50) = 1.58$, $p < .13$.[5]

Errors. As an initial step, trials on which errors occurred were removed from the data set. To this end, we started with five categories of errors: task unrelated (e.g., when environmental noises triggered the voice relay); miss trials (when a subject did not see the target pair); uncorrected error trials (when a subject said the distractor letter); corrected error trials (when a subject corrected his or her output before the onset of the next pair); and short-latency responses (occurring within 100 ms of the offset of the letter pair). These errors were determined by listening to a tape recording of each subject's performance.[6] Because there were too few errors in each of these subcategories to analyze them separately, we collapsed across the categories to produce a total error score in each condition. These error rates are shown in Table 1. A 2 × 2 (Ages × Trial Types [sequential vs. control]) mixed analysis of variance (ANOVA) was performed on errors. Older adults made more errors than younger adults, $F(1, 51) = 5.76$, $MS_e = 67.2$, $p < .03$, and subjects made more errors on sequential than on control trials, $F(1, 51) = 21.06$, $MS_e = 12.3$, $p < .001$. The interaction between age and trial type was not significant, $F < 1$. There was no evidence, for either younger or older subjects, of a speed/accuracy trade-off.

Reaction time. All remaining scores were then averaged within sequential and control trials to produce two reaction time measures per subject. These means are given in Table 1. Reaction times were subjected to a 2 × 2 (Ages × Trial Types [sequential vs. control]) mixed ANOVA. As is apparent from Table 1, older adults were reliably slower than younger adults, $F(1, 51) = 8.63$, $p < .01$, $MS_e = 9727.7$. Overall, responses on sequential trials were slower than those on control trials, $F(1, 51) = 14.38$, $p < .01$, $MS_e = 58$. Of particular relevance to the present hypothesis was the reliable interaction between Age and Trial Type, $F(1, 51) = 4.78$, $p < .04$. Post hoc tests revealed significant (8.9 ms) slowing for younger adults on sequential compared with control trials, $F(1, 24) = 24.50$, $p < .01$, $MS_e = 40.03$. This slowing is of the order of magnitude reported elsewhere (e.g., Neumann & DeSchepper, 1989a, Experiments 2 and 3; Tipper & Cranston, 1985, Experiment 2), although larger effects have also been reported with different sorts of materials (e.g., Neill & Westberry, 1987, Experiment 2; Tipper, 1985; Tipper & Cranston, 1985, Experiment 3). Thus, young adults in the present study demonstrate the now frequently reported "negative priming" effect thought to be associated with suppressing an unselected stimulus on a previous selection trial. No such suppression effect was found for older adults, $F(1, 27) = 1.07$, whose net difference between sequential and control trials was only 2.4 ms.

Awareness. Because only 2 older adults became aware of the sequential patterns of trials, we focus here on the performance of 5 younger adults who were aware of the sequential dependencies in the experimental lists. Aware subjects were slower than unaware subjects on both sequential (327.9 ms and 284.4 ms, respectively) and control (320.5 ms and 275.5 ms, respectively) trials, $t(28) = 1.96$ and 2.01, respectively, $ps < .06$. However, their mean inhibition score (7.4 ms) did not differ from that of unaware subjects (8.9 ms), $t(28) < 1$. These two groups of younger subjects also did not differ on any other measured dimension, including Age, Education, Vocabulary, Errors, and self-reported Emphasis on Accuracy (largest $t = 1.77$, $ps > .09$).

The present data are quite straightforward in showing the presence of suppression effects for younger adults, a finding that replicates the work of many investigators (e.g., Tipper, 1985; Tipper & Cranston, 1985). What is important here is the absence of a detectable suppression effect for older adults.

Experiment 2

Neill and Westberry (1987, Experiment 2) traced the time course of inhibition using Stroop materials by varying the interval between the response made on one trial and the onset of stimuli on the next trial. Their data suggested, for young subjects, that the time course of inhibition follows a pattern of a buildup from 20 to 520 ms, followed by a decline thereafter from 520 ms to 1,020 ms to 2,020 ms. Inhibition was assumed by those investigators to passively dissipate over

[5] One subject gave no speed/accuracy ratio and so is not included in this analysis.

[6] Another less time-consuming scoring procedure has been introduced by Neumann and DeSchepper (1989b). They eliminated all scores greater than 2,000 ms and less than 200 ms as well as scores on trials following such deletions. In addition, they removed scores greater than 5 standard deviations from each condition's mean. The present data were rescored using a very similar method. All scores under 50 ms from the offset of the target were deleted, as were scores greater than 5 standard deviations and the immediately following trials. We also took out trials on which subjects did not see the stimulus display. The correlations between the two scoring techniques—that used in the text and that described here—are .99 for both sequential and control trials for both expriments. No conclusions would have been altered using this less time-consuming scoring procedure.

time. In the present experiment, we extended the response-to-stimulus onset interval to 1,200 ms. Our expectation for young subjects was that performance would be consistent with that reported by Neill and Westberry in showing a decline in the amount of inhibition.

With respect to older adults, the increased response-to-stimulus interval might be an opportunity for an inhibitory system that is slow or inefficient, or both, to build up to detectable levels of activity. This view is consistent with a broad range of findings showing older adults to be slower than younger adults on a wide range of tasks (e.g., Salthouse, 1982). Thus, our expectation was the reverse of the pattern of data found for Experiment 1: We now expected to see less suppression for younger adults and measurable suppression for older adults. In neither of these instances were our expectations confirmed. Indeed, the data suggest quite a different picture than hitherto seen of the time course of inhibition, while adding support to the finding from the first experiment that older adults have reduced inhibition.

Method

Subjects. Thirty younger (range = 18–22 years, M = 18.7 years) and 30 older (range = 62–75 years, M = 69.0 years) adults were tested. All the younger subjects were recruited from an introductory psychology course. Older subjects were recruited from the same source as in the first experiment and were paid for their participation. Five younger subjects were replaced because of equipment failures.

Procedures. The major procedural change was introduced by the increase in the response-to-stimulus onset interval. This was adjusted by lengthening the exposure duration of the white fixation crosses from 500 to 1,200 ms. An additional change was that the vocabulary test was given first in the sequence of events rather than last. In all other respects, the procedures and materials of Experiment 2 were identical to those of Experiment 1.

Results

Subject comparisons. One older and 9 younger subjects were aware of the list structure. Their data, together with that of one older participant who had a deviantly high rate of errors (26%), were deleted. The mean ages of the remaining 21 younger subjects and 28 older subjects were 18.6 and 68.6 years, respectively. The older subjects had more years of education (16.1) than did the younger subjects (13.2), $t(47) = 4.67$, $p < .01$, as well as a higher mean on the Shipley-Hartford vocabulary test (36.0 vs. 33.0), $t(47) = 3.12$, $p < .01$). Older and younger subjects did not differ in the relative emphasis they reported placing on accuracy (60.2% vs. 55.3%), $t(42) = 1.05$.[7] Differences in education and vocabulary scores had little relation to the measure of inhibition, $rs = -.10$ and $-.21$, respectively.

Errors. Table 1 shows the mean proportion of errors for younger and older subjects on sequential and control trials. As in Experiment 1, errors were subjected to a 2 × 2 ANOVA. Here again, there were main effects of Age, $F(1, 47) = 14.36$, $MS_e = 56.3$, and Trial Type, $F(1, 47) = 7.13$, $MS_e = 7.3$, $p < .02$, but no interaction, $F < 1$. Again, although errors differed with age, there was no evidence of a speed/accuracy trade-off for either younger or older adults.

Reaction time. All trials having errors were deleted, and the remaining scores were then averaged for sequential and for control trials. The resulting mean reaction times may be seen in Table 1. A 2 × 2 mixed ANOVA showed a pattern of results similar to that seen in Experiment 1. Older adults were slower than were younger adults, $F(1, 47) = 9.21$, $p < .01$, $MS_e = 13213.6$. The absence of an overall difference between sequential and control trials, $F(1, 47) = 1.58$, is attributable to the reliable interaction between Age and Trial Type, $F(1, 47) = 4.16$, $p < .05$, $MS_e = 125.2$. Again, younger adults showed a significant inhibition effect (of 7.5 ms), $F(1, 20) = 20.02$, $p < .01$, $MS_e = 29.72$, that is comparable to that seen in Experiment 1. By contrast, older adults still showed no evidence of reliable inhibition (−1.8 ms), $F(1, 27) < 1$, $MS_e = 195.9$.

It is clear that a longer intertrial interval does not necessarily permit the buildup of inhibition for older adults. They continue to show no carryover effects across successive sequential trials. Although somewhat unexpected, these findings, like those of Experiment 1, are consistent with the hypothesis advanced by Hasher and Zacks (1988) that, relative to younger adults, older adults show reduced inhibition in the context of selective-attention tasks.

More surprising here, based on expectations from the work of Neill and Westberry (1987), is the absence of any evidence of diminution of inhibition for young adults across the lengthened intertrial interval. Although Neill and Westberry did not actually test subjects at the present intervals, testing instead at 20, 520, 1,020, and 2,020 ms, interpolation from their Figure 1 leads to the expectation of a decline. Our data suggest another source for declines in suppression: strategies adopted by subjects who become aware of the sequential nature of experimental trials. We thus considered the possibility that awareness played a substantial role in performance at the present response-to-stimulus onset interval.

Awareness. An inspection of the data of the 9 aware, younger subjects is particularly revealing. They took a mean of 302.9 ms to respond on control trials and a shorter mean of 291.8 ms to respond on sequential trials. This produced a facilitation on sequential trials of 11.1 ms, an effect that was not significant, $t(8) = 1.54$, $p < .16$, although 7 of 9 subjects showed facilitation. However, because the overall inhibition score includes performance on both early trials, during which subjects were probably unaware, as well as later trials, during which they were aware, an analysis of inhibition scores on just the trials in the second half of the experiment was performed. Facilitation was now 32.8 ms and was marginally significant, $t(8) = 2.28$, $p = .052$. Thus, young adults who were aware of the nature of the relationship across successive sequential trials actually tended to be faster on those trials than on control trials. These subjects were able to use their knowledge of the irrelevant letter on one trial to speed their production of that letter's name on the next trial. The aware subjects in the present study did not differ from unaware subjects in Age, Education, Vocabulary, Errors, or self-reported Emphasis on Accuracy, largest $t(28) = 1.53$, $p > .13$.

[7] Five subjects gave no speed/accuracy ratio and so are not included in this analysis.

Although facilitation on sequential trials has been reported for subjects who were urged to be quick rather than accurate in responding (Neill & Westberry, 1987, Experiment 1; Neumann & DeSchepper, 1989b), our aware subjects did not have faster reaction times overall than their unaware agemates, $t(28) < 1$. Instead, 1,200 ms between trials appears to be sufficient to permit some subjects to become aware and for aware subjects to use their knowledge of the unselected letter on one trial to prepare for a speeded response to that letter on the next trial. Further consideration of the data of the 5 young, aware subjects of Experiment 1 supports the latter point. Recall that these subjects did not show facilitation; they actually produced an inhibition score of 7.4 ms, which was not different from that of unaware subjects. Apparently, the 500 ms available to subjects in Experiment 1 permitted a small number of subjects to become aware of the relations across sequential trials, but it was not sufficient time for those subjects to successfully use this knowledge. An analysis of inhibition scores for only the second half of the trials confirms this. The inhibition scores for aware and unaware subjects were not significantly different at the 500-ms response-to-stimulus onset interval, $t(28) = 1.15$. The data also suggest that the number of subjects who become aware increases with the intertrial interval.

Crossexperiment comparisons. The pattern of performance in Experiment 2 suggests the possibility that evidence interpreted as decay of inhibition may be produced by collapsing across data from two groups of subjects (aware and unaware), particularly in long intertrial-interval conditions. To assess this possibility, we considered the data of all young subjects, aware and unaware, in both experiments. These means are reported in Table 2. A 2 × 2 (Intervals [500 ms vs. 1,200 ms] × Conditions [sequential vs. control]) mixed ANOVA was conducted on reaction times. The small overall difference between sequential and control trials was still reliable, $F(1, 58) = 10.21$, $p < .01$, $MS_e = 81.9$. The difference in response-to-stimulus onset intervals did not impact on performance as a main effect, $F < 1$, although as can be seen, there was a reliable interaction between the time interval and the trial conditions, $F(1, 58) = 4.08$, $p < .05$, $MS_e = 81.9$.

Simple effects revealed that the difference between sequential and control trials was reliable at a 500-ms interval between response and stimulus onset (Experiment 1), $F(1, 29) = 27.3$, $p < .01$, $MS_e = 40.82$. However, that same difference was no longer reliable at 1,200 ms (Experiment 2), $F(1, 29) < 1$. This is precisely the pattern that would be predicted by interpolating from Figure 1 of Neill and Westberry (1987). However, if only data from unaware subjects are considered, the present findings show stability of suppression effects across increasing response-to-stimulus onset intervals.

Table 2
Mean Reaction Times and Proportion of Errors (in parentheses) for Sequential and Control Trials for All Younger Participants Experiments 1 and 2

Experiment	Sequential	Control	Inhibition
1 (RSI = 500 ms)	291.6 (.051)	283.0 (.032)	8.6
2 (RSI = 1,200 ms)	296.7 (.037)	294.7 (.024)	2.0

Note. RSI = response-to-stimulus onset interval. For both experiments, $n = 30$.

General Discussion

The present experiments address two empirical issues regarding the role of suppression in selective attention: (a) the time course of suppression effects, and (b) age differences in suppression effects across the adult lifespan. The findings are quite straightforward. Suppression effects were maintained for young, unaware subjects as the response-to-stimulus onset interval increased from 500 to 1,200 ms. Recently, persistent inhibition has been found for even longer intervals (Stoltzfus, Hasher, Zacks, & Smith, 1990; Tipper, Weaver, Cameron, Brehaut, & Bastedo, 1990), raising the question of when or how inhibition does actually dissipate. One possibility is that release from inhibition may require that a response actually be made to the previously suppressed stimulus or to some other stimulus or event.

With respect to age differences, the data are also straightforward: Younger adults show a suppression or negative priming effect that is comparable to that reported elsewhere (Neumann & DeSchepper, 1989a; Tipper & Cranston, 1985, Experiment 2). Older adults, however, show no negative priming. Unlike the younger adults, older adults were able to select an item on one trial without that choice having a measurable consequence for the unselected item when that item subsequently served as the target. This result was obtained even in Experiment 2 in which the response-to-stimulus onset interval was lengthened in an attempt to allow the effect of what might be a sluggish inhibitory system to become manifest.

The absence of a carryover effect (either positive or negative) from one sequential trial to the next for older adults might suggest that they were not processing the distractor letter while selecting the target. Recall, however, that the task itself gave no clue as to the position in which the target letter would occur on each trial. Presumably, subjects had to fixate on the center of the screen to be prepared to find the target at either spatial location. Further, there was not sufficient time, once the two letters appeared, for subjects to make an eye movement from one letter to the other should the first letter have been the incorrect one. Therefore, if subjects could accurately select the target, they must also have processed the distractor to some extent. The error rate of older adults, although higher than that of younger adults, affected only 6% to 7% of trials, confirming that older adults were indeed processing both stimuli on most trials.

Two other findings are consistent with the view that older adults processed the unselected stimulus term. First, we have found, using the same exposure conditions as in these experiments, that both older and younger adults are slower to respond on trials on which a subject must select and name one letter of two compared with trials on which subjects name a single letter occurring in one of two locations (Stoltzfus et al., 1990; see also McDowd & Oseas, 1990; Tipper, 1990). Clearly, the presence of a second letter causes interference for older participants, as it does for younger participants.

Second, there is also recent evidence that older adults, like younger adults, can benefit from the presence of a distractor that repeats across several selection trials of the sort used in the present experiment (McDowd & Oseas, 1990). Facilitation on such trials suggests that older subjects acquired information about the identity of the distractor on one trial that made it easier to ignore that distractor on the next.

Although older adults can consistently select a target, they show no residual effects of their exposure to a distracting stimulus on a subsequent naming trial (see also McDowd & Oseas, 1990; Tipper, 1990). This finding suggests that there are age differences in the mechanisms, particularly those involving suppression, that are thought to underlie selective attention, or more specifically, the consequences of selective attention. The second experiment suggests that the problem for older adults is not with a suppression system that is itself slowed; a longer response-to-stimulus onset interval does not permit a detectable buildup of suppression for the unselected item.[8]

We turn now to an account of these findings that ties them to a recent model interrelating attention, memory, and language (Hasher & Zacks, 1988). In this model, a central focus is on the mechanisms that control access to activated (Cowan, 1988) or working memory, or both. Centrally important is a suppression process that acts on stimuli that are off the goal path as determined by the objective task or by the motives of the subject, or by both. These inhibitory mechanisms operate at encoding, to influence the range of contents of working or activated memory, as well as at retrieval, when they determine the breadth of search paths through memory. Hasher and Zacks (1988) speculated, on the basis of existing findings in the attention, memory, and language literatures, that older adults have attentional deficiencies in the mechanisms that control access to activation. A diminished inhibitory system will permit, at the time of input, an "enriched" memory that is working or activated or both, because fewer stimuli will be excluded from consideration. As well, irrelevant stimuli that are activated will receive richer processing because they will not be as effectively dampened, as can occur with a more efficient suppression system. Finally, at retrieval, inefficient inhibition will also prevent the dampening of activation along irrelevant retrieval pathways.

Consistent with the prediction of enriched activation is recent evidence that shows that, relative to younger adults, older adults are more likely to consider interpretations of material they are reading that are not central to the objective meaning of a passage (Hamm & Hasher, 1990). They also are more likely to maintain alternative interpretations even when they have been contradicted or superseded by new information (Hamm & Hasher, 1990; Hartman & Hasher, 1990).

The theory also predicts that reduced suppression will be associated with heightened levels of competition at retrieval (e.g., Anderson, 1983; Postman & Underwood, 1973) for older subjects. Their lack of inhibitory effectiveness will allow a large number of traces to become associated while simultaneously active in working memory. Heightened competition may also be the result of the inability to suppress irrelevant ideas at retrieval. Recent evidence suggests that older adults are, in fact, differentially susceptible to competition effects (Gerard, Zacks, Hasher, & Radvansky, in press; Winocur, Moscovitch, & Witherspoon, 1987).

Thus, diminished inhibitory efficiency may be a central mechanism underlying both the heightened distractibility and poor recall often reported for older adults. From the perspective of this model, the present findings represent the first direct evidence of age-related declines in what may be a basic mechanism of selective attention.

We turn now to consider selective attention and the role of suppression processes. Negative priming results are taken as evidence that the process of selecting one stimulus from an array also entails the suppression of one or more unselected elements. The present data suggest that selection can occur without necessarily engaging suppression for unselected items (contrast Navon, 1987; Neumann, 1984), because older subjects can select the target yet show no distractor suppression. Similar findings have been reported by Tipper, Borque, Anderson, and Brehaut (1989) in research with second-grade children. Although selection may be possible without inhibition, one consequence of diminished suppression might well be reduced efficiency of selection (see McDowd & Oseas, 1990; Tipper, 1990). Indeed there is evidence that people who score high on a questionnaire that indexes absent-mindedness also show less suppression (Tipper & Baylis, 1987). As well, if evidence of widespread and sustained activation of inappropriate meanings can be taken as evidence of the failure of inhibitory control, as we and others have suggested (Neill, 1989), then there is evidence of individual differences in suppression among both children (Merrill, Sperber, & McCauley, 1981) and young adults (Gernsbacher & Faust, 1990; Gernsbacher, Varner, & Faust, 1990).

The present findings appear to confirm a central assumption of the Hasher and Zacks (1988) theory: the existence of age differences in inhibition at the level of selective attention. Although most often thought of as occurring during the presentation of information, mechanisms of selective attention probably play a role at retrieval as well, at least insofar as choices must be made along the search path between relevant and irrelevant responses to retrieval cues. Thus, older adults (and others) may be impaired both at input and at retrieval by inefficient inhibitory mechanisms enabling activation of irrelevant ideas or search paths that ultimately slow or impede retrieval of target facts.

[8] On the basis of the persistence of inhibition for younger adults across the two response-to-stimulus onset intervals, it seems unlikely that the absence of negative priming for older adults can be accounted for by suggesting that what inhibition older adults have builds up quickly and is dissipated by the time we attempted to measure it.

References

Anderson, J. R. (1983). *Architecture of cognition*. Cambridge, MA: Harvard University Press.

Cowan, N. (1988). Evolving conceptions of storage, selective attention, and their mutual constraints within the information-processing system. *Psychological Bulletin, 104*, 163–191.

Gerard, L., Zacks, R. T., Hasher, L., & Radvansky, G. A. (in press).

Age deficits in retrieval: The fan effect. Journal of Gerontology: Psychological Science.

Gernsbacher, M. A., & Faust, M. E. (1990). *Less-skilled comprehenders have less-efficient suppression mechanisms.* Manuscript submitted for publication.

Gernsbacher, M. A., Varner, K. R., & Faust, M. E. (1990). Investigating differences in general comprehension skill. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16,* 430–445.

Gold, D., Andres, D., Arbuckle, T., & Schwartzman, A. (1988). Measurement and correlates of verbosity in elderly people. *Journal of Gerontology, 43,* 27–33.

Hamm, V. P., & Hasher, L. (1990). *Age and inferences.* Manuscript submitted for publication.

Hartman, M., & Hasher, L. (1990). *Age differences in indirect memory for relevant and irrelevant words.* Manuscript submitted for publication.

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

Keele, S. W., & Neill, W. T. (1978). Mechanisms of attention. In E. C. Carterette & M. P. Friedman (Eds.), *Handbook of perception* (Vol. 9, pp. 3–47). New York: Academic Press.

Layton, B. (1975). Perceptual noise and aging. *Psychological Bulletin, 82,* 875–883.

Lowe, D. G. (1985). Further investigations of inhibitory mechanisms in attention. *Memory & Cognition, 13,* 74–80.

Madden, D. J. (1983). Aging and distraction by highly familiar stimuli during visual search. *Developmental Psychology, 19,* 499–507.

McDowd, J. M., & Oseas, D. M. (1990). *Aging, inhibitory processes, and negative priming.* Manuscript submitted for publication.

Merrill, E. C., Sperber, R. D., & McCauley, C. (1981). Differences in semantic encoding as a function of reading comprehension skill. *Memory & Cognition, 9,* 618–624.

Mueller, J. H., Kausler, D. H., Faherty, A., & Oliveri, M. (1980). Reaction time as a function of age, anxiety, and typicality. *Bulletin of the Psychonomic Society, 16,* 473–476.

Navon, D. (1987). *Visibility or disability: Notes on attention.* (ICS report 86-06). San Diego: University of California.

Neill, W. T. (1977). Inhibitory and facilitatory processes in selective attention. *Journal of Experimental Psychology: Human Perception and Performance, 3,* 444–450.

Neill, W. T. (1979). Switching attention within and between categories: Evidence for intracategory inhibition. *Memory & Cognition, 7,* 283–290.

Neill, W. T. (1989). Lexical ambiguity and context: An activation-suppression model. In D. S. Gorfein (Ed.), *Resolving semantic ambiguity* (pp. 63–83). New York: Springer-Verlag.

Neill, W. T., & Westberry, R. L. (1987). Selective attention and the suppression of cognitive noise. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13,* 327–334.

Neumann, E., & DeSchepper, B. G. (1989a). *Costs and benefits of distractor inhibition in selective attention.* Manuscript submitted for publication.

Neumann, E., & DeSchepper, B. G. (1989b). *An inhibition-based fan effect: Evidence for an active suppression mechanism in selective attention.* Manuscript submitted for publication.

Neumann, O. (1984). Automatic processing: A review of recent findings and a plea for an old theory. In W. Prinz & A. F. Sanders (Eds.), *Cognition and motor processes* (pp. 255–293). Berlin, Germany: Springer-Verlag.

Obler, L. K. (1980). Narrative discourse style in the elderly. In L. K. Obler & M. L. Albert (Eds.), *Language and communication in the elderly* (pp. 75–90). Lexington, MA: Heath.

Postman, L., & Underwood, B. J. (1973). Critical issues in interference theory. *Memory & Cognition, 1,* 19–40.

Salthouse, T. A. (1982). *Adult cognition: An experimental psychology of human aging.* New York: Springer-Verlag.

Stoltzfus, E. R., Hasher, L., Zacks, R. T., & Smith, M. (1990). *Development of interference and suppression effects.* Manuscript in preparation.

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. (1990). *Less attentional selectivity as a result of declining inhibition in older adults.* Manuscript submitted for publication.

Tipper, S. P., & Baylis, G. C. (1987). Individual differences in selective attention: The relation of priming and interference to cognitive failure. *Personality and Individual Differences, 8,* 667–675.

Tipper, S. P., Borque, T. A., Anderson, S. H., & Brehaut, J. C. (1989). Mechanisms of attention: A developmental study. *Journal of Experimental Child Psychology, 48,* 353–378.

Tipper, S. P., & Cranston, M. (1985). Selective attention and priming: Inhibitory and facilitatory effects of ignored primes. *The Quarterly Journal of Experimental Psychology, 37A,* 591–611.

Tipper, S. P., & Driver, J. (1988). Negative priming between pictures and words: Evidence for semantic processing of ignored stimuli. *Memory & Cognition, 16,* 64–70.

Tipper, S. P., Weaver, B., Cameron, S., Brehaut, J. C., & Bastedo, J. (1990). *Inhibitory mechanisms in identification and localization tasks: Time course and disruption of inhibition.* Manuscript in preparation.

Winocur, G., Moscovitch, M., & Witherspoon, D. (1987). Contextual cueing and memory performance in brain-damaged amensics and old people. *Brain & Cognition, 6,* 129–141.

Winthorpe, C., & Rabbitt, P. (1988). Working memory capacity, IQ, age and the ability to recount autobiographical events. In M. M. Gruneberg, P. E. Morris, & R. N. Sykes (Eds.), *Practical aspects of memory: Current research and issues, Vol. II. Clinical and educational implications.* Chichester, England: Wiley.

Received April 12, 1990
Revision received July 16, 1990
Accepted July 17, 1990 ■