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Investigations of Inhibition and Interference in Younger and Older Adults

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Previous work (Hasher, Stoltzfus, Zacks, & Rypma, 1991) suggested the existence of adult age-related differences in the ability to suppress or inhibit irrelevant information. This investigation explored age differences in the time course of suppression. Experiments 1 and 2 showed that younger adults demonstrate the same level of suppression at 300 as they do at 1,700 ms after a selection response. Older adults consistently show no suppression. Experiments 2 and 3 also examined the relationship between suppression and the degree to which distractors interfere with concurrent selection. The absence of a reliable relationship — both within and across age groups — together with other findings in the literature, raise questions about the function of suppression as a mechanism of concurrent selection. Another function, one that aids in the establishment of a coherent thought stream, is proposed.

THEORIES of selective attention attempt to explain how a subset of information can be efficiently processed when it appears amidst irrelevant information. Traditionally, emphasis in attention theories has been placed on the processing of target or selected information, which is presumed to be enhanced relative to unselected information. The fate of the unselected information itself has seemed relatively less important, largely because of the assumption that it simply passively decays (e.g., Broadbent, 1982; LaBerge, 1983; Treisman, 1986).

However, there are now several theories of selective attention (e.g., Keele & Neill, 1978; Neill, 1977; Tipper, 1985) that propose an active suppression or inhibition process that operates directly on unselected or distracting information during selection. (See Appendix, Note 1.) In these views, efficient selection is obtained not only by enhancing availability of selected information, but also by suppressing representations of, or responses to, irrelevant information. Thus, representations of nonselected information may be actively disattended in such a way as to decouple one stream of information from response mechanisms, thus facilitating responses to selected information and slowing responses to irrelevant (or decoupled) information (Allport, Tipper, & Chmiel, 1985; Navon, 1989a, 1989b; Neumann, 1987).

One line of evidence consistent with this inhibition view comes from attention tasks that require selective responding to a target stimulus that appears along with one or more similar distracting stimuli. For example, a subject's task might be to name the red letter that appears in an array of one red and one green letter. On critical sequences of trials, the distractor stimulus on one trial becomes the target stimulus on the subsequent trial (i.e., the identity of the green letter on a first trial is the same as the identity of the red letter on a second trial). As many studies have now shown (e.g., Lowe, 1979; Neill, 1977; Tipper, 1985), responses to such target items are slowed, compared with control trials on which the target had not just served as the previous distractor. The source of this slowing, sometimes called "negative priming," is thought to be the inhibition that has accrued to the current target during its service as a distractor on the previous trial.

Several investigations have explored the nature of this inhibition effect. Tipper (1985), for example, has shown that the inhibition effect extends to semantic associates of ignored information. The inhibition effect also does not depend on perceptual features of the stimuli; inhibition was still present when the distractor on the priming trial was a word and the subsequent semantically related target was a picture (Tipper & Driver, 1988). Other studies have demonstrated that the effect is not dependent on a specific motor response (Neill, Lissner, & Beck, 1990) or even a particular response modality, as it transfers across vocal and manual responses (Tipper, MacQueen, & Brehaut, 1988). These observations suggest that the inhibition occurs at a central rather than peripheral point in the selection-response sequence. (See Appendix, Note 2.)

Hasher, Stoltzfus, Zacks, and Rypma (1991) recently reported that older adults did not show a suppression effect in these selection tasks, suggesting that they do not inhibit selected-against or irrelevant information to the same extent as do younger adults (see also McDowd & Oseas-Kreger, 1991; Tipper, 1991). This lack of suppression is particularly interesting because it could be related to the difficulty that older adults routinely have in selective attention tasks. There is evidence, for example, that older adults are differentially impaired on a variety of visual search tasks that require responding to a target that appears unpredictably in the midst of nontarget stimuli (e.g., Plude & Hoyer, 1985; Rabbitt, 1965). The Hasher et al. data suggest that this impairment may stem from deficiencies in inhibitory processes that would otherwise operate on irrelevant or interfering items during attentional selection.

Hasher and Zacks (1988) have hypothesized that an impairment in efficient suppression of irrelevant or marginally relevant information is a basis of not only attentional deficits, but also many of the memory and language comprehension failures experienced by older adults (and potentially by other individuals as well). For example, in a text processing situation, older adults appear to have difficulty suppressing previously generated, but no longer relevant inferences (Hamm & Hasher, 1992). They also show heightened memory for irrelevant information under some circumstances (Hartman & Hasher, 1991; Kausler & Kleim, 1978; Radvansky, Zacks, & Hasher, 1991; Shaw, Rypma, & Toffle, 1992). As well, older adults also are disadvantaged in recall — a problem that may well be due to competition among unsuccessfully suppressed irrelevant ideas and targets (Gerard, Zacks, Hasher, & Radvansky, 1991).

Thus, the finding that negative priming, or distractor suppression, is absent in several samples of older adults may be of considerable significance in accounting for age differences in cognition. However, further tests of the generality of these findings are important, because several variables have been shown to influence the magnitude of suppression effects, even in younger adults. One such variable involves the time course over which suppression may develop and dissipate. Neill and Westberry (1987) explored the time course of suppression in younger adults by changing the time between response to the first stimulus, or priming trial, and presentation of the subsequent stimulus (the response-to-stimulus interval or RSI). Their data show a small, nonsignificant buildup of inhibition from a 20-ms RSI to a 520-ms RSI, followed by a reliable decline starting between the 520- and 2,020-ms intervals. Similarly, Yee (1991) has shown that inhibition requires some time to build up after selection on the priming trial. Because older adults are generally slower than younger adults on a broad range of tasks (Cerella, 1985; Salthouse, 1982), it is possible that inhibition builds up at a slower rate for older than for younger adults. If so, older adults may well show inhibition but only beyond the intervals tested thus far, the longest being 1,200 ms in Hasher et al. (1991).

Alternatively, suppression may develop at comparable rates for older and younger adults, but may dissipate more quickly for older adults than for younger adults. If this were true, the attention problem for older adults would be the maintenance of suppression rather than its development. In this case, existing studies may have tested too late in the time course of selection (500 ms being the earliest RSI tested), when suppression may have already dissipated for older adults.

The present investigation addresses these two possibilities concerning age differences in the time course of inhibition in younger and older adults. In particular, our initial concern was to determine whether older adults would show inhibition later (Experiment 1) or earlier (Experiment 2) in the time course of selection than previous studies had considered.

A secondary question to be addressed concerns the fundamental issue of the function of inhibition in selective attention. Current views suggest that the suppression effect is evidence of an inhibitory process that works in the service of *concurrent* selection. That is, suppression of irrelevant information *allows* or *aids in* selection of targets by keeping distractors from being selected and/or from having access to response mechanisms. Tipper, Weaver, Cameron, Brehaut, and Bastedo (1991a), for example, cite two mechanisms involved in selective responding: excitation and inhibition. Together, these mechanisms are thought to achieve efficient selection by enhancing or activating target information and by making concurrent distracting information less available. This reasoning leads to some predictions about selection performance, as noted by Tipper, Weaver, Kirkpatrick, and Lewis (1991b), "Competing distractors, which are substantially inhibited, should result in two observations: first, greater negative priming, assuming that negative priming reflects inhibition: and second, less interference due to greater inhibition of the competing to-be-ignored representations."

However, not all studies in the negative priming literature have supported a simple negative relationship between amount of interference and amount of inhibition. Although some find support for this notion (Tipper, 1991; Tipper & Baylis, 1987; Tipper, Bourque, Anderson, & Brehaut, 1989), others have failed to find such a relationship either for groups of subjects, across individuals, or across experiment conditions (Beech, Baylis, Smithson, & Claridge, 1989a; Beech & Claridge, 1987; Driver & Tipper, 1989; Flowers, Heppner, & Muraoka, 1990; Tipper et al., 1991b). The current studies further explored group and individual differences in inhibition and interference using the letter-naming suppression task we used in previous studies (Hasher et al., 1991).

Experiment 1

Younger and older adults participated in a reaction time task in which they were asked to name a target letter that appeared with a distractor letter. Targets always appeared in one color (either red or green) and distractors appeared in the other color. On trials in the Control condition, unique letters served as targets and distractors across pairs of trials. On trials in the Distractor Suppression condition, however, the letter that was ignored on one trial became the target on the subsequent trial. (See Appendix, Note 3.) Here we used a 1,700-ms interval between naming response and stimulus presentation on the assumption that older adults need more time to develop measurable inhibition than has so far been accorded them.

Method

Design and subjects. — The design consisted of the between-subjects factor of Age (Older vs Younger adults) and the within-subjects factor of Trial Type (Distractor Suppression vs Control).

Thirty-eight younger adults (mean age 18.8 years, range 17–23) and 26 older adults (mean age 69.3 years, range 63–76) participated in Experiment 1. Younger subjects were Duke University undergraduates fulfilling a course requirement. Healthy, high-functioning older subjects were obtained through the Duke University Center for the Study of Aging and Human Development and were paid $10.00 plus parking expenses. Although no formal test for color blindness was administered, none of the younger or older subjects reported any difficulty in discriminating red from green. Five younger and two older subjects were replaced due to equipment failures.

Materials. — Materials for the letter-naming task were identical to those used in Hasher et al. (1991). Stimuli consisted of 12 letters (A, B, C, D, E, J, K, N, O, S, T, and V) presented in pairs on the screen of an AT-type computer with an EGA card. Each letter pair contained one red and one green letter which appeared in fixed locations on the screen. The target letter appeared in each of the two possible positions approximately equally often. The letters themselves were 6 mm high and 6 mm wide, with a distance of 6 mm between the letters. Subjects sat approximately 75 cm away from the screen so that the entire two-letter display subtended a horizontal visual angle of 1.37°.

The letter pairs were presented in lists of 10 trials each. Half of the lists were Distractor Suppression lists containing trials in which the previous distractor letter became the target on the current trial. The other half of the lists were Control lists containing pairs of letters that were unrelated to the previous or subsequent pair. Subjects received 24 Control lists and 24 Distractor Suppression lists in a semi-random order, such that each type of list could occur no more than six times in succession.

In order to minimize awareness of sequential relationships between trials, the sequence from the 1st to 2nd trial and from the 9th to 10th trial on each list was randomly determined. Therefore, data from only the 3rd through 9th trials in a list were analyzed, leaving 168 trials per condition in the experiment. Further details regarding list construction are outlined in Hasher et al. (1991).

Procedure. — Procedures were also identical to those used in Hasher et al. (1991). Subjects were seated in front of a computer screen and were told that they would be seeing a number of two-letter displays, each with a red and a green letter. Half of the subjects were instructed to name the red letter and half the green letter as quickly and as accurately as they could. The distractor letter was to be ignored.

The sequence of a trial was as follows: (a) two fixation crosses appeared on the screen for 1,700 ms; (b) the fixation crosses were replaced by two letters, one red and one green, which appeared for 200 ms; and (c) the letters were replaced by asterisk masks that appeared in the colors of the letters they replaced. The masks remained on the screen until the subject responded by naming the target letter. Immediately after the subject's response to one trial, fixation crosses appeared for the next trial. Response times were recorded by the computer from the offset of the letter pair to the onset of a vocal response.

After subjects were familiarized with the sequence of events in a trial, they received practice using the voice-activated relay and were given five practice lists (consisting of Control-type trials only) before beginning the experiment proper. After completing the experimental series of trials, subjects were queried about their awareness of the sequential letter pattern that appeared across Distractor Suppression trials, and about strategies they might have used in the task. They were also asked to give a ratio describing the relative emphasis they placed on accuracy vs speed during the letter-naming task (e.g., an equal 50%–50% or a 75%–25% emphasis on speed). At the end of the session, subjects took the Shipley-Hartford Vocabulary Test. The entire session lasted approximately 55 minutes for younger and 75 minutes for older subjects.

Results and Discussion

Subject comparisons. — During the questioning phase of the experiment session, 17 younger and two older subjects reported that they noticed the relationship between trials on the Distractor Suppression lists during the letter-naming task. (See Appendix, Note 4). Because previous studies have shown that these "aware" subjects show a different pattern than "unaware" subjects in negative priming tasks (Allport et al., 1985; Hasher et al., 1991), their data were eliminated from the analyses. (See Appendix, Note 5.) All results reported are for the remaining unaware subjects (21 younger and 24 older adults).

The mean age of the remaining older adults was 69.0 years (range 63–76); that of the younger adults was 18.8 years (range 17–23). The older adults had significantly more years of education than the younger adults, $t(43) = 2.37$, $p < .03$ (means 14.9 and 13.7 years, respectively), as well as a marginally higher mean Shipley-Hartford Vocabulary score, $t(43) = 1.98$, $p < .06$ (means 35.2 and 32.6, respectively). Older adults also had a nonsignificant tendency to report placing more emphasis on accuracy than younger adults in the letter-naming task, $t(42) = 1.80$, $p < .09$ (means 71.0 and 63.0, respectively). (See Appendix, Note 6.) Emphasis on accuracy, however, was not correlated with the suppression measure in either younger ($r = .016$) or older ($r = .110$) adults.

Errors. — Responses were considered errors and removed from the response time analysis if subjects gave an incorrect naming response or if the voice-activated relay failed to register the subject's response appropriately. In addition, all response times less than 100 ms were considered errors. The number of errors in each of these categories was too low to do separate analyses for each type of error, so overall error rates are reported for all conditions and ages, as shown in Table 1.

A 2 × 2 repeated measures analysis of variance (ANOVA) with Age (Old vs Young) and Trial Type (Dis-

Table 1. Mean Reaction Times and Error Rates (in Parentheses) for Younger and Older Unaware Adults by Trial Type in Experiment 1

Group	n	Condition: Distractor Suppression	Condition: Control	Inhibition Effect
Younger	21	329 (.036)	319 (.030)	10
Older	24	417 (.069)	416 (.065)	1

tractor Suppression vs Control) as factors was performed on letter-naming errors. The significance level was set at p = .05 for all analyses.

Older subjects had a significantly higher error rate overall (.067) than younger subjects (.032), $F(1,43) = 10.35$, $MS_e = .003$. Participants made equal numbers of errors on Distractor Suppression and Control trials, $F(1,43) = 1.43$, and there was no interaction between Age and Trial Type, $F(1,43) < 1$.

Reaction time. — Several different methods of response time scoring have been used in various negative priming studies in the literature. Here we used two methods of scoring in each data set: the first method involved the exclusion of all error trials listed above, whereas the second method also excluded the trial immediately following any trial on which a subject gave an incorrect response. Because both methods of scoring produced identical results, only the response times from the first scoring system are reported.

Reaction times (see Table 1) were submitted to a 2 × 2 repeated measures ANOVA identical to that described above for errors. Older adults were slower than younger adults, $F(1,43) = 12.09$, $MS_e = 15798.9$, and responses on Distractor Suppression trials were slower than on Control trials, $F(1,43) = 8.91$, $MS_e = 70.3$. As in previous work (Hasher et al., 1991), the interaction between Age and Trial Type was also significant, $F(1,43) = 6.47$, $MS_e = 70.3$. Post-hoc comparisons showed that young subjects were reliably slower on Distractor Suppression trials than Control trials, $F(1,20) = 11.93$, $p < .001$, showing a suppression effect of 10 ms. Older subjects, however, showed a nonsignificant suppression effect of 1 ms, $F(1,23) < 1$.

Experiment 1 replicates previous aging studies showing reliable inhibition in negative priming tasks for younger but not for older adults (Hasher et al., 1991; McDowd & Oseas-Kreger, 1991; Tipper, 1991). The present results, combined with findings reported by Hasher et al., do not reveal any increase in inhibition from a 500-ms RSI to a 1,700-ms RSI, as might be expected if inhibition built up more slowly for older adults than for younger adults. Older adults simply fail to show reliable inhibition at any interval tested thus far.

Experiment 1 also confirmed that younger adults show a distractor suppression effect for a relatively long time after a response is made in a letter-naming task (Tipper et al., 1991a).

Experiment 2

Experiment 1 showed that older adults do not develop distractor suppression in the relatively long 1,700-ms interval after selection of a target stimulus from a two-letter array. Distractor suppression in older adults has not, however, been tested at very short RSIs. Although suppression does not build up with time for older adults, it could be argued that it develops quickly, as it does for younger adults, but that only younger adults are able to maintain that inhibition. If this were so, inhibition might exhibit a pattern of decline in older adults, a decline that might start before the earliest interval at which suppression has been tested thus far (500 ms). In Experiment 2, a very short RSI was chosen (300 ms) in order to rule out the possibility that inhibition for older adults is present only very early after selection.

Experiment 2 also included an additional condition so that the extent to which subjects were distracted by the presence of an irrelevant letter could be measured. In this condition, subjects named a single letter in the absence of a second, distracting letter. By subtracting naming time without distraction from naming time with distraction (the condition called "Control" in Experiment 1), an interference score could be derived. If the extent to which subjects are slowed by the presence of interfering information is determined by the extent to which they are able to inhibit that information, then older adults (who so far show no inhibition) should show a large amount of interference. In addition, for at least younger adults, amount of interference should be negatively correlated with inhibition.

Method

Design and subjects. — The design in Experiment 2 was similar to that of Experiment 1, with the addition of the No Distraction condition as a level of the within-subjects variable Trial Type.

Thirty-one younger (mean age 18.4 years, range 17–21) and 28 older (mean age 70.1 years, range 63–77) adults participated in Experiment 2. Younger and older subjects were from the same sources as those in Experiment 1. One younger and three older subjects were replaced because of failure to follow instructions in the letter-naming task. Eight additional subjects (three younger and five older) were replaced due to equipment failures and lost data.

Materials. — Materials for the Distractor Suppression and Control conditions were identical to those used in Experiment 1. For the No Distraction condition, new Control lists were constructed (using algorithms similar to those used for Control lists in Experiment 1) and then the spaces that would have been occupied by distractor letters were replaced by blank spaces. Subjects therefore saw only one letter on the screen at a time, and its location (left vs right of center) was unpredictable. For each subject, the color of the single letter was always the same as that of the target color used for all preceding trials. Four practice and four test lists in the No Distraction condition were created in this way for each subject, yielding 28 No Distraction condition reaction times for a subject.

Procedure. — Procedures for Experiment 2 were identical to those in Experiment 1, with two exceptions. First, the RSI was shortened from 1,700 ms in Experiment 1 to 300 ms in Experiment 2. Second, the single letter-naming task was added after the main task.

Results and Discussion

Subject comparisons. — Three younger subjects were aware of the sequential manipulation in the letter-naming task, and their data were eliminated from all analyses. Three older subjects were excluded because of high letter-naming error rates (all had error rates higher than 20%). All results reported are for the remaining 28 younger and 26 older adults.

The mean age of older adults was 70.0 years (range 63–77) and of younger adults was 18.5 years (range 18–21). Older adults had more years of education than younger adults, $t(52) = 4.16, p < .001$ (means 16.0 and 13.5 years, respectively), as well as a higher mean Shipley-Hartford Vocabulary score, $t(52) = 2.25, p < .03$ (means 35.0 and 32.6, respectively). Older and younger adults did not differ in their self-reported emphasis on accuracy in the letter-naming task, $t(52) < 1$ (means 55% and 57%, respectively).

Errors. — Based on the findings of Experiment 1 and of Hasher et al. (1991), specific predictions could be made regarding patterns of performance for younger and older adults. Therefore, within-group differences on the error and response time measures were analyzed using planned comparisons. The error rates for younger and older subjects in all conditions are shown in Table 2. Younger adults made marginally more errors on Distractor Suppression than on Control trials, $F(1,27) = 4.16, MS_e = .001, p < .06$, but made no more errors on Control than No Distraction trials, $F(1,27) < 1$. Older adults made equal numbers of errors on Distractor Suppression and Control trials, $F(1,25) < 1$, but made reliably more errors on Control than No Distraction trials, $F(1,25) = 24.76, MS_e = .003$, suggesting the presence of some interference in the error measure for older adults. Error rate interference was not related to amount of inhibition or interference on the response time measure for older adults ($rs = -.178$ and $-.182$).

Reaction time. — On the response time measure, younger adults showed a reliable suppression effect (8 ms) for Distractor Suppression vs Control trials, $F(1,27) = 31.41, MS_e = 63.83$, and a reliable interference effect (47 ms) for No Distraction vs Control trials, $F(1,27) = 59.84, MS_e = 1034.37$. Distractor Suppression and Control trials were not different for older adults, $F(1,25) < 1$, confirming the absence of a suppression effect. Older subjects did show a reliable difference between Control and No Distraction trials, $F(1,25) = 41.91, MS_e = 1170.16$, demonstrating a significant interference effect of 44 ms. This response time interference effect was no larger for older than for younger adults, suggesting that subjects from the two age groups did not differ in the average slowdown caused by the presence of a distractor letter. The results certainly do not strongly support the less inhibition-greater interference hypothesis.

Table 2. Mean Reaction Times and Error Rates (in Parentheses) for Younger and Older Unaware Adults by Trial Type in Experiment 2

Group	n	Condition: Distractor Suppression	Control	No Distractor	Inhibition	Interference
Younger	28	316 (.039)	308 (.026)	261 (.023)	8	47
Older	26	335 (.104)	335 (.096)	291 (.036)	0	44

Individual differences. — As a further test of the relationship between inhibition and interference, correlations were obtained between these two selection measures within and across subject groups. For each subject an inhibition score was obtained by subtracting the mean response time on Control trials from the mean response time on Distractor Suppression trials. Likewise, an interference score was obtained by subtracting the No Distraction mean from the Control mean for each subject. The inhibition and interference scores were then correlated within both age groups separately, and then across all subjects. None of these correlations proved significant (highest $r = -.294, p > .12$).

In addition to the simple correlational analyses, additional analyses were performed to assess the lack of relationship between interference and inhibition effects, without using the effect scores themselves, which have some undesirable properties (e.g., they are generally less reliable than the raw reaction time scores themselves). This analysis involved use of a partialling technique (see Glenberg, 1990), in which the base response time was partialled out of the No Distraction and Distractor Suppression conditions in order to get a better measure of the effects due to interference and inhibition. Regression equations were first generated to predict the No Distraction and Distractor Suppression trial response times from the Control response times for each of the younger and older adult subjects. These equations were then used to generate No Distraction and Distractor Suppression scores for each subject within each age group. The predicted response times for these conditions were then subtracted from the observed scores (resulting in a partialled score), and the resulting partialled scores were then correlated. The correlation for older adults was .054 and for younger adults was .291 (both nonsignificant), again suggesting the absence of a relationship between inhibition and interference.

The converging results of the individual differences analyses suggest that the relationship between inhibition and interference is not a simple and consistent one, given the lack of consistent relation between the effects due to inhibition and those due to interference both within and across subject groups.

Cross-experiment comparisons of suppression. — Data from the unaware subjects from the present investigation (Experiments 1 and 2) and from two preceding studies (Hasher et al., 1991, Experiments 1 and 2) were combined into one large data set to explore potential differences in the amount of inhibition across the various RSIs (Figure 1). Each of these data sets was collected with subjects from the identical subject pools, and within a limited time period. In addition, the identical materials and procedures were used across the four studies.

A 2 Ages × 4 RSIs × 2 Trial Types repeated measures ANOVA was performed on response times. As anticipated, there were main effects of Age, $F(1,193) = 34.57, MS_e = 10594.1, p < .01$, Trial Type, $F(1,193) = 27.65, MS_e = 76.0, p < .01$, and RSI, $F(3,193) = 6.22, MS_e = 10594.1, p < .01$ on response time. The only reliable interaction was that between Age and Trial Type, $F(1,193) = 21.51, MS_e = 76.0, p < .01$, confirming that suppression effects are different for older and younger adults. This pattern did not

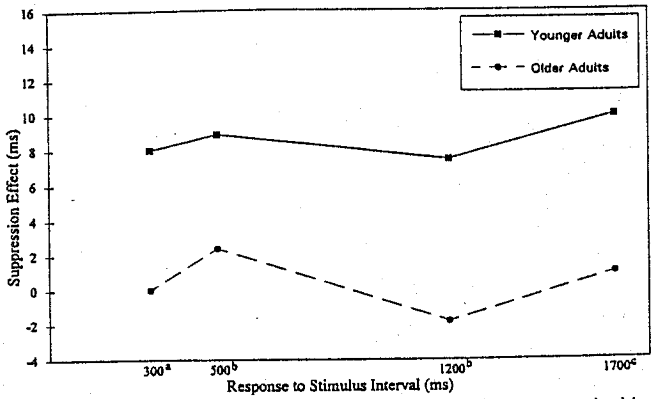

Figure 1. Time course of suppression effects for younger and older unaware subjects across four RSIs. [a]Data from Experiment 2. [b]Data from Hasher et al. (1991), Experiments 1 and 2. [c]Data from Experiment 1.

vary across RSIs for either younger or older adults. Suppression effects remained constant for both age groups, with younger adults demonstrating reliable suppression at all RSIs and older adults failing to do so at any RSI.

In summary, Experiment 2 revealed significant suppression for younger, but not older adults at a very short (300 ms) RSI. Inhibition does not appear to build up for older adults and then decay quickly; rather, as the cross-experiment comparisons showed, inhibition to a distractor is not detectable at all for older adults at any interval from 300 to 1,700 ms after a response is made to a target stimulus. Younger adults, on the other hand, show reliable suppression at a surprisingly stable level across all of these intervals.

Although the age differences in inhibition might be anticipated from previous work, the findings regarding the relationship between interference and inhibition did not support views suggesting that suppression and interference are complementary. Instead, the amount of interference obtained did not appear to depend on the degree to which suppression was engaged. Older and younger adults showed equivalent amounts of interference on the reaction time measure, with greater interference for older adults shown only on the error measure. In addition, correlational analyses of the suppression and interference effects suggest no direct relationship between the two measures within or across age groups.

Experiment 3

In a follow-up experiment we further explored the finding of an absence of a relationship between inhibition and interference with an additional group of younger adults. In this study we used three interference measures, one internal and two external to the basic letter-naming task. The new interference measures were from the classic Stroop (1935) task and from a reading task that involved reading aloud a target text that was either printed alone or embedded amidst distracting text (Willows & MacKinnon, 1973). The additional measures allowed us to explore, within the younger adult population, the relationship between the ability to suppress and the ability to ignore irrelevant information across multiple selection tasks.

Method

Subjects. — The 40 subjects in Experiment 3 were undergraduates who were working at the Duke University campus during the summer session. These subjects were recruited through campus advertisements and were paid $10 for their participation.

Materials. — The materials for the letter-naming task were identical to those used in Experiment 2.

For the Stroop task, the traditional Word, Color, and Color-word cards were used. The stimuli were printed on three 8½ × 11-inch cards. Each card had items arranged in 10 columns with 10 rows each, for a total of 100 experimental items. There was one practice row of 10 items at the top of each card. Color cards had blocks of red, blue, and green, each 4 mm high and 8 mm wide. Word cards had the same color names printed in black ink in lower case letters that were 2.5 mm high. Color-word cards had the names of the three colors (red, blue, and green) printed in colored inks (red, blue, and green). Color-words were always different from the hues in which they were printed. For each card type the color names, hues, or name-hue combinations were used approximately equally often.

Materials for the reading task were selected from those used by Connelly, Hasher, and Zacks (1991). Subjects read two test passages: one with distracting material interspersed among the words on each line of target text (Experimental Condition), and one with no such distracting material (Control Condition). Passages were typed in black ink on 8½ × 11-inch pages, one story per page. Target text was typed in italics, and distracting material, when present, was typed in upright text.

Two different stories were used, and subjects got each story in either its Experimental or Control version. The distracting text for each story consisted of four unique words or phrases that were related to the target material in the text. Each word or phrase was repeated 15 times within the distracting text and also appeared as a foil answer to one of four multiple-choice comprehension questions that each subject answered after reading the story. Data from the comprehension test are not reported here, because previous work (Connelly et al., 1991) has shown that this particular measure of comprehension is not sensitive to the presence or absence of distracting text, as is reading time.

Procedure. — Procedures for the letter-naming task were identical to those used in Experiment 2, except that the RSI was 500 ms, the interval used in Hasher et al. (1991), Experiment 1.

For the Stroop task, subjects always saw cards in the following order: Word, Color, Color-word. Subjects began each card by reading a row of practice items. For the test trials, the experimenter then said "Begin," and the subject started reading the words or naming the colors across each row. On the Color-word card, subjects were told to say the name of the hue of each word and ignore the word itself. Subjects were told that if they made errors, they should correct themselves and go on. Color and word naming times for each card were measured by the experimenter with a stopwatch.

For the reading task, subjects first received a control story as practice (all subjects read the same practice story). Subjects then read two more stories, one Control passage and one Experimental passage, with half of the subjects receiving the Control story first and half the Experimental story first. The experimenter handed the subject each story in a face-down position. When the experimenter said "Begin," subjects turned over the page and began reading aloud, starting with the title. Subjects were instructed to read at their normal reading speed and to ignore any upright text when it appeared because it was irrelevant. The experimenter measured reading times with a stopwatch. After each story subjects answered four comprehension questions.

RESULTS AND DISCUSSION

Subject information. — Subjects had a mean age of 19.7 years (range 17–22) and 14.4 years of education. Their mean Shipley-Hartford score was 35.9. Seven of the 40 subjects were aware of the sequential relationship between trials on the Distractor Repetition lists, and their data are not reported for any of the measures.

Letter-naming task. — As performance predictions could be made based on the results of younger subjects from Experiments 1 and 2, the error and reaction time data were again analyzed using planned comparisons, with $p < .05$.

Errors in letter-naming were treated just as before; all error trials were removed from the reaction time analysis. Subjects had marginally higher error rates on Distractor Suppression (.032) than Control trials (.027), $F(1,32) = 3.17$, $MS_e = .00016$, $p < .09$, but had similar error rates on Control and No Distraction (.016) trials, $F(1,32) = 1.59$.

In the reaction time analysis, Distractor Suppression trials (M = 304 ms) were responded to more slowly than Control trials (M = 294 ms), $F(1,32) = 69.70$, $MS_e = 49.79$, with subjects showing a 10-ms suppression effect. Subjects were slower on Control than No Distraction trials (M = 244 ms), $F(1,32) = 29.93$, $MS_e = 2748.1$, revealing 50 ms of letter-naming interference. The patterns of errors, interference, and suppression shown here are similar to the patterns seen for younger adults in Experiments 1 and 2.

Stroop task. — Response time means for the Word, Color, and Color-word cards were 38 seconds, 53 seconds, and 88 seconds, respectively, and card condition had a reliable effect on response time, $F(2,64) = 305.95$, $MS_e = 70.5$, $p < .001$. The only post-hoc comparison of interest was the Color-word vs Color card (the interference comparison), which showed a reliable interference effect of 35 seconds, $F(1,32) = 239.84$, $MS_e = 170.03$, $p < .001$. These subjects, therefore, showed the common finding of interference in color-naming when the color and word aspects of the stimulus are incompatible.

Reading task. — Subjects were reliably slower to read Experimental (463 ms/word) than Control (297 ms/word) passages, $F(1,32) = 133.85$, $MS_e = 3406.3$, $p < .001$, revealing an interference effect of 166 ms/word. These results are similar to those reported by Connelly et al. (1991), confirming that subjects are slowed by the presence of distracting text during reading.

Table 3. Correlations Between Interference and Inhibition for Younger Adults in Experiment 3 Using the Correlational (Above) and Partialling (Below) Techniques

Selection Measures	2	3	4
1. Letter-naming interference	.380* .304	.075 −.009	−.040 .002
2. Stroop interference	—	.124 .148	−.162 −.118
3. Reading interference		—	.098 .030
4. Letter-naming inhibition			—

*$p < .05$.

Correlational analyses. — Response time interference scores were calculated in each of the three tasks for each subject, and then correlated across tasks and with the inhibition effect. In addition, the same partialling method used in Experiment 2 was used here to generate similar correlations between the effects due to inhibition and interference.

As can be seen in Table 3, Stroop interference and letter-naming interference were significantly correlated using one correlational method, but the reading interference score did not correlate with either Stroop interference or letter-naming interference. None of these interference scores correlated with the inhibition effect in the letter-naming task. Thus, inhibition was not correlated with interference within or across tasks. Indeed, the interference measures themselves were not consistently correlated across tasks (see also Broadbent, Broadbent, & Jones, 1986, for similar findings), suggesting that interference in various tasks may arise from different sources. This observation raises the question of whether inhibition would be expected to be related to interference when interference itself is relatively unstable for individuals within groups. Susceptibility to interference for an individual, then, may be the result of a complex interaction of task and stimulus factors, with inhibitory ability only a single component in the equation. The findings from this study then, taken with those from Experiment 2, suggest that interference is not always the simple product of the inefficiency of a suppression mechanism that operates concurrently to enable selection.

General Discussion

The first two experiments reported here explored the time course of suppression in younger and older adults. Adding to the work of Hasher et al. (1991), these studies reveal, for younger adults, no decay or buildup of letter-naming suppression from 300 to 1,700 ms after an overt selection response is made. This nondecay pattern for suppression effects is consistent with data reported by Tipper et al. (1991a) and by DeSchepper and Treisman (1991) with very different materials and procedures.

A similar time course invariance is seen here for older adults who show no evidence at all of an inhibition effect at any of the intervals tested. These data suggest that previous failures to find suppression in older adults (Hasher et al., 1991; McDowd & Oseas-Kreger, 1991; Tipper, 1991) were not due to age differences in the time course of suppression during selection tasks; older adults simply do not appear to suppress responses to irrelevant or selected-against items in the course of selecting and responding to a target. In fact, recent work has shown that older adults do not appear to suppress distractor responses as well as younger adults, even after hundreds of selection trials using the same set of distractors repeatedly in a consistent mapping search task (Fisk, Rogers, & Giambra, 1990; Rogers & Fisk, 1991) or a version of the Stroop task (Dulaney & Rogers, 1992). We note, however, that in the present studies older adults are, nonetheless, able to select one target from two items, demonstrating that selection itself is entirely possible in the absence of suppression.

The invariance of suppression effects across RSIs for young adults here and in other studies (Hasher et al., 1991; Tipper et al., 1991a) stands in direct contrast to decay patterns reported by Neill and his colleagues (Neill & Valdes, 1992; Neill & Westberry, 1987). The reason for this discrepancy is not at all clear, although Neill and Valdes suggest that a basic experimental design choice may be critical. To date, between-subjects RSI comparisons have shown no decay, at least for subjects who are unaware of stimulus relations across trials (Hasher et al., 1991). Within-subject comparisons, in contrast, have shown a pattern of decay (Neill & Valdes; Neill & Westberry). The ultimate explanation of such different patterns may, as Neill and Valdes suggest, be tied to subject strategies, or they may be tied to other unassessed differences in methodology. In any event, careful exploration of these discrepant patterns of findings is clearly warranted in future research.

We turn now to the findings involving the interference measures from Experiments 2 and 3. As discussed earlier, the notion of inhibition as necessary for concurrent selection predicts that individuals or groups who show small amounts of inhibition should show large amounts of interference. In Experiment 2, however, older adults showed no evidence of suppression and yet older and younger adults showed similar amounts of response time interference from a distractor letter. Although the possibility of a speed/accuracy tradeoff in the older adult group makes the data less clear, the correlational analyses of inhibition and interference clearly showed no relationship between suppression and distraction within either the younger or older groups (or across age groups). Experiment 3 confirmed this result with another group of younger adults using the letter-naming task, as well as two other tasks thought to index interference from irrelevant stimuli.

As noted earlier, the existing literature on suppression effects suggests that the relationship between interference and inhibition is far from straightforward. Groups of subjects who show less inhibition do not always show more interference relative to a control group of subjects (Beech et al., 1989a; Beech, Powell, McWilliam, & Claridge, 1989b; Westberry, 1983). The few studies that report direct correlations between interference and inhibition are also inconsistent in their findings. Beech et al. (1989a), for example, report significant negative correlations across their schizotypal and nonschizotypal subject groups, but not in all conditions. Beech and Claridge (1987) and Flowers et al. (1990) find no such correlation at all. Further, a lack of relationship between inhibition and interference across task conditions was noted by Driver and Tipper (1989), who reported evidence of inhibition in younger adults under selection conditions that produce interference as well as under those that do not (see also Allport et al., 1985; Tipper et al., 1991a, 1991b). Taken together, data from between-group, within-group, and across condition comparisons of suppression and interference effects provide less than strong support for the supposition that inhibition inevitably functions to reduce interference during concurrent selection. Clearly, selection is multiply determined.

If inhibition does not always serve to aid concurrent selection, might it have an additional or alternative attentional function? One possibility is that inhibition helps to maintain activation (or sustain attention) toward an already selected target by decreasing the probability that attention will return to a rejected distractor. In this way, suppression may be a loose conceptual analogue of a perceptual phenomenon, inhibition of return, first reported by Posner and Cohen (1984). Inhibition of return is a spatial inhibitory attentional mechanism that helps to orient attention toward useful future (locational) information, rather than toward past locations. For "conceptual" inhibition of return, the function would be to enable the organism to develop ideas along a selected train of thought without returning to already rejected thoughts. Such a conception of the function of inhibition makes its long duration for younger adults seem reasonable: after all, long-lasting suppression of already rejected distractors would enable a single train of thought to be further developed, unhindered by potentially recurring distraction.

If downstream development of coherent thought and action tendencies does indeed depend on suppression, its apparent absence in older adults should then be associated with a relative inability to maintain a selected line of thought, coupled with evidence of no longer relevant information continuing to influence and perhaps even to disrupt current processing. A number of recent studies of speech production are consistent with the view that older adults have greater difficulty maintaining a line of coherent thought (e.g., Gold, Andres, Arbuckle, & Schwartzman, 1988; Kemper, Rash, Kynette, & Norman, 1990). As well, there is evidence that older adults have greater difficulty abandoning no longer relevant information as effectively as younger adults do. This has been found with interpretations made in the course of reading garden path stories (Hamm & Hasher, 1992), with words generated as endings for high Cloze-value sentences that have unexpected endings (Hartman & Hasher, 1991), as well as for "forget" words in a directed forgetting task (Radvansky et al., 1991). (See Appendix, Note 7.) The inability to exclude, via suppression, no longer relevant information would also presumably result in differential susceptibility to proactive interference (Dempster, 1990; Winocur & Moscovitch, 1983) and, in fact, current evidence on adult age differences in forgetting is consistent with this view (Gerard et al., 1991).

Thus, suppression may be a mechanism that permits thoughts and actions to remain coherent despite the presence (and recurrence) of irrelevant environmental stimuli and associatively elicited irrelevant or tangential thoughts. Its absence, or diminution, can be expected to have profound implications across a range of cognitive functions, from language comprehension and speech production to forgetting and reasoning.

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Appendix — Notes

1. We use the terms "suppression" and "inhibition" interchangeably throughout.
2. Another theory about the inhibition effect has tried to explain the slowdown as being the result of some sort of mismatch between conflicting information which is present on successive trials (Allport et al., 1985; Lowe, 1985). This explanation, however, has not been able to account for all of the findings in the literature (Dalrymple-Alford & Budayr, 1966; Tipper & Cranston, 1985). A similar version of this hypothesis has recently been suggested by Neill and Valdes (1992).
3. The Distractor Suppression condition was termed the "Sequential" condition in Hasher et al. (1991).
4. We note that older subjects appear to be much less likely to become aware than younger adults. This was also true in our previous work with this task.
5. Hasher et al. (1991) reported that subjects who became aware of the sequential manipulation showed marginal *facilitation* (rather than inhibition) on some of the experimental trials when the RSI was sufficiently long (1,200 ms). Aware subjects in the present study showed a similar pattern of performance: a tendency to shift from inhibition to facilitation on Distractor Suppression trials.
6. The number of subjects in this *t*-test is 44 rather than 45, because one subject could not give a speed/accuracy ratio and thus was not included in this analysis.
7. A similar inability to suppress irrelevant information has been found in poor comprehenders (Gernsbacher & Faust, 1991).