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Below-Baseline Suppression of Competitors During Interference Resolution by Younger but Not Older Adults

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Abstract

Resolving interference from competing memories is a critical factor in efficient memory retrieval, and several accounts of cognitive aging suggest that difficulty resolving interference may underlie memory deficits such as those seen in the elderly. Although many researchers have suggested that the ability to suppress competitors is a key factor in resolving interference, the evidence supporting this claim has been the subject of debate. Here, we present a new paradigm and results demonstrating that for younger adults, a single retrieval attempt is sufficient to suppress competitors to below-baseline levels of accessibility even though the competitors are never explicitly presented. The extent to which individual younger adults suppressed competitors predicted their performance on a memory span task. In a second experiment, older adults showed no evidence of suppression, which supports the theory that older adults' memory deficits are related to impaired suppression.

Keywords

memory, semantic memory, attention, cognitive ability, individual differences

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Many researchers, including ourselves, have argued that selecting among competing memories during retrieval entails suppressing the competitors, basing this argument on evidence that rejecting a competitor reduces its subsequent accessibility (Anderson & Spellman, 1995; Aslan & Bäuml, 2011; Healey, Campbell, Hasher, & Ossher, 2010; Norman, Newman, & Detre, 2007; Storm, 2011). In a typical suppression paradigm, both targets and competitors are primed in an initial study phase (e.g., Anderson & Green, 2001; Anderson & Spellman, 1995). After priming, participants attempt to retrieve targets in the face of interference from the competitors. On a final accessibility task (e.g., recall, speeded naming), targets typically retain the accessibility boost from the priming phase, whereas competitors lose some, or even all, of that boost. That is, suppression is manifest as a reduction of initial priming. There have been few demonstrations of below-baseline suppression, which should be the hallmark of a true suppression effect. Here, we introduce a new paradigm that eliminates the priming phase so that competitors are at baseline accessibility prior to the retrieval attempt. The results show that among young adults, a single retrieval attempt is sufficient to produce below-baseline suppression of competitors. Furthermore, the extent to which individuals suppress competitors in this task predicts their performance on the operation span (OSpan) task, a well-validated measure of memory (Conway et al., 2005).

In a second experiment, we replicated the below-baseline suppression effect with a new sample of young adults and tested the hypothesis that older adults do not suppress competitors. Older adults are known to have difficulty resolving interference (Campbell, Hasher, & Thomas, 2010; Hasher & Zacks, 1988; Hulicka, 1967; Ikier & Hasher, 2006; Ikier, Yang, & Hasher, 2008; Kane & Hasher, 1995; Winocur & Moscovitch, 1983), and several

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accounts of cognitive aging suggest that this difficulty is due to impaired suppression mechanisms (i.e., the inhibitory theory of aging; Hasher, Lustig, & Zacks, 2007; Hasher & Zacks, 1988). Results for the younger adults replicated the results of Experiment 1, and, as predicted by inhibitory theory, older adults showed no evidence of suppressing competitors.

Experiment 1

Method

This experiment began with a word-generation task, in which participants were presented with a long list of cue words. A task instruction was presented 250 ms after the appearance of each cue word. On some trials (*related* trials), the instruction signaled participants to produce a strong associate of the cue; on other trials (*unrelated* trials), the instruction signaled them to produce a weak associate of the cue. Because visually presented words automatically activate their meaning within 250 ms (Neely, 1977; Rabovsky, Sommer, & Abdel Rahman, 2012), and because participants did not know which task was required of them until after this time window, we predicted that strong associates would be activated in both conditions but that the initial activation would have to be suppressed in the unrelated condition in order for participants to produce an appropriate response. To test if the strong associates were indeed suppressed, we used a second task, speeded word naming, to measure their accessibility. The list for the word-naming task included the closest associates (targets) of the cue words from the generation task along with control words that were unrelated to any previously presented words. If selecting a weak associate involves suppressing strong associates, participants should be slower to name targets from unrelated trials than they are to name targets from related trials or control words.

Participants. Fifty-two university students (mean age = 19.73 years, *SD* = 2.54) who were native English speakers participated for course credit.

Stimuli. We selected 60 cue-target pairs (e.g., *hive-bee*) that had high cue-to-target associations but normatively weaker target-to-cue (backward) associations. To create the pairs, we began with all the nouns from the University of South Florida Free Association database (Nelson, McEvoy, & Schreiber, 1998). We paired each target word with its strongest cue. We eliminated pairs that did not have naming-time norms in the English Lexicon Project database (Balota et al., 2007). We then excluded pairs with cue-to-target associations less than .5 and target-to-cue associations greater than .2. We also eliminated items with frequencies more than 3 standard deviations from the mean of surviving items. The resulting 60 pairs were divided into three 20-pair lists in a fully counterbalanced fashion (for a full list of the pairs, see Table S1 in the Supplemental Material available online). We equated the lists on forward and backward association strength, word length, word frequency, normed naming time, standard deviation of normed naming time, concreteness, and the strength of the next highest cue-to-target association. We attempted to set the maximum difference between lists on any variable to less than 1 standard error of the mean of the whole pool of 60 pairs, and this goal was achieved for forward association, word length, mean naming time, and concreteness, and nearly achieved for the other variables. For each participant, the three lists were randomly assigned to the related, unrelated, and control conditions, with list-condition assignments being counterbalanced across participants.

Procedure. During the word-generation task, each cue word was presented alone for 250 ms, after which a task instruction, indicating whether a related or unrelated word was to be generated, appeared above the cue word. On related trials, participants were instructed to say "the first word that comes to mind that is meaningfully related or strongly associated to the cue word." On unrelated trials, they were instructed to produce a word "that has as little relationship with the cue word as possible." The cue word remained on-screen until a response was given; the response was followed by a 1,500-ms interstimulus interval (ISI). Twenty trials of each type were randomly intermixed. Within each 10-trial block of this task, there were 5 related and 5 unrelated trials in random order, with the constraint that no more than 2 trials of the same type occurred consecutively. A single random order was used for all participants.

After the word-generation task, participants completed a word-naming task. During the word-naming task, participants read each of a series of words as quickly as possible. This series included the targets from the related and unrelated cue-target pairs (*related* and *unrelated targets*, respectively), as well as the targets from the nonpresented cue-target pairs (*control words*). Note that the related targets had likely been considered as possible responses during the generation task, whereas the unrelated targets should have been suppressed during the generation task; items from the counterbalanced control list were unlikely to have come to mind during the generation task. In addition to the targets, 100 filler words were presented. Each word was presented until a response was given, and the response was followed by a 1,500-ms ISI. This task began with 8 filler items, and the remaining items were divided into four blocks. Within each block, 5 related targets, 5 unrelated targets, 5 control words, and 23 filler items were presented in random order, with the constraint that no more than 2 critical items (related or unrelated targets) appeared consecutively. We used Latent Semantic Analysis (Landauer & Dumais, 1997) to ensure that the filler words were not strongly related to any cues, targets, or control words.

Participants then completed the OSpan task (the version described in Conway et al., 2005). On each trial, two to five words were presented. Each word was preceded by a simple math equation, which participants had to verify. At the end of the trial, participants attempted to recall the words in serial order.

Data processing. Differences in mean reaction time (RT) across conditions are quite sensitive to even a small number of fast or slow outlying responses (Ratcliff, 1979). Therefore, we employed a trimming scheme designed to reduce the influence of such outliers without eliminating valid responses (see Ratcliff, 1993, for a discussion of RT trimming methods). For each participant and within each condition, we first eliminated any RTs faster than 200 ms or slower than 2,000 ms (0.56% and 0.29% of responses, respectively). After we excluded these extreme values, any remaining values more than 2.5 standard deviations from the mean were replaced with a value equal to the mean plus or minus 2.5 standard deviations (0.23% of responses per participant, on average). The total trimming rate was approximately 1% of responses, well below the 5% to 15% rates found to be acceptable for detecting true differences in means in Monte Carlo studies (Ratcliff, 1993).

Results and discussion

Naming time. On unrelated trials, participants saw cue words (e.g., *hive*) and had to avoid producing the associated target words (e.g., *bee*). If doing so required suppressing the target words, naming times for these targets should subsequently have been slowed. On related trials, participants were not required to reject the targets. Therefore, naming times for these targets should not have been slowed. We assessed slowing by comparing the naming times for targets with naming time for counterbalanced control words, which were unrelated to any cues presented in the word-generation task. Figure 1a shows the mean naming times, with 95% within-subjects confidence intervals.

The critical question was whether naming was slowed for the targets in the unrelated condition. As the nonoverlapping confidence intervals indicate, naming of unrelated targets was indeed slower than naming of either control words or related targets—evidence that selecting a weak associate of a cue involved suppressing a strong associate of the cue. The means for the control words and related targets were not significantly different.

In most suppression paradigms, competitors are primed prior to interference resolution, and suppression reduces that priming (Anderson & Green, 2001; Anderson

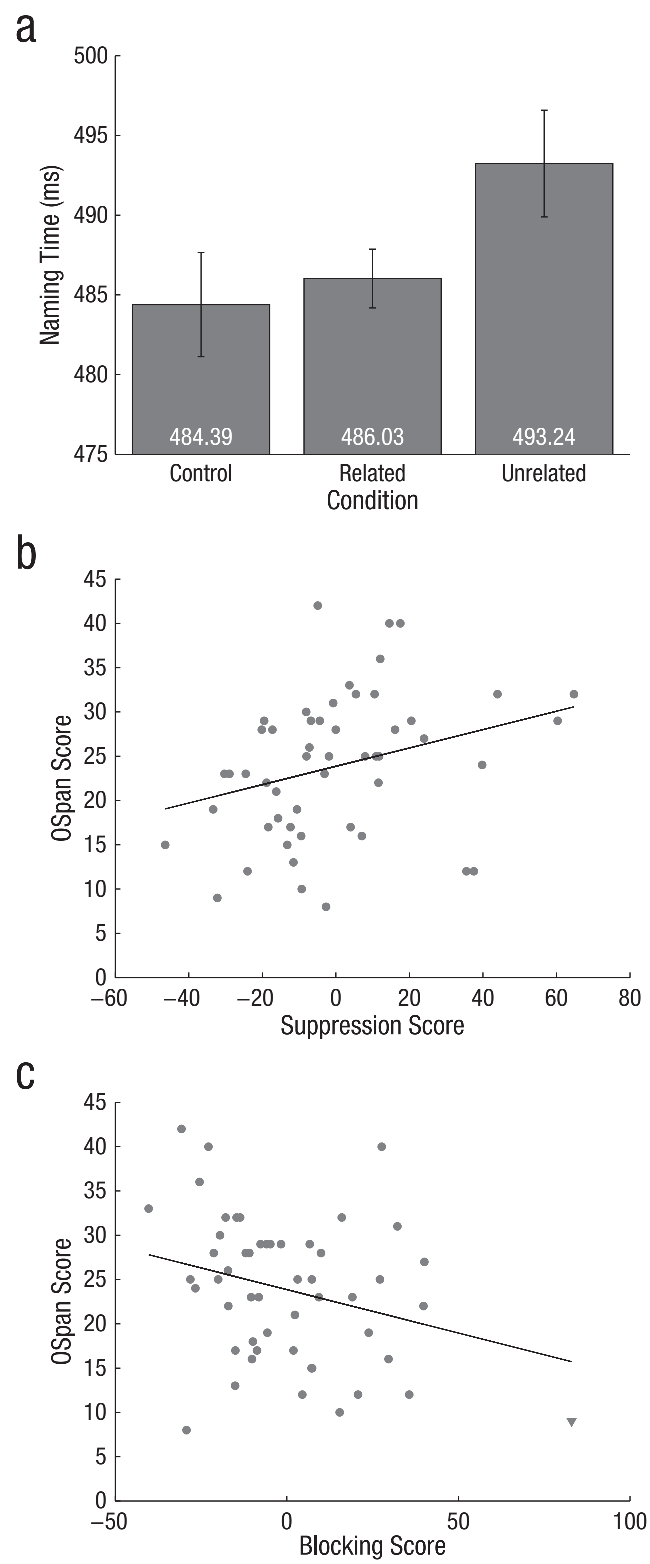

Fig. 1. Results from Experiment 1. The bar graph (a) shows mean naming times in the three conditions. Error bars are 95% confidence intervals calculated using Masson and Loftus's (2003) method for within-subjects designs. Means with nonoverlapping error bars are significantly different at the .05 level. The scatter plots (with least-squares regression lines) show the association of operation span (OSpan) scores with (b) suppression scores and (c) blocking scores. In (c), the triangular data point in the lower right corner is a likely outlier that was removed from the final analyses reported in the text.

& Spellman, 1995; Blaxton & Neely, 1983; Healey et al., 2010; Higgins & Johnson, 2009; Radvansky, Zacks, & Hasher, 2005; Storm, 2011). That is, although competitors are less accessible than control items, their net accessibility generally *increases* from the beginning of the experiment to the end. Here, we observed a net *decrease* of competitor accessibility. Thus, the results constitute some of the strongest evidence available for the role of suppression in retrieval.

Correlations with OSpan performance: suppression versus episodic blocking. If the slowing effect we observed does indeed reflect the resolution of memory interference, then individuals who show more slowing in this paradigm, and thus stronger suppression, should perform better on memory tasks, relative to individuals who show less slowing. To test this prediction, we correlated individual differences in the slowing effect with performance on the OSpan task, which, along with other complex span tasks, is known to be vulnerable to interference (Bunting, 2006; May, Hasher, & Kane, 1999; Rowe, Hasher, & Turcotte, 2008). This analysis also allowed us to test an alternative account of the slowing effect: episodic blocking.

During each trial of the word-generation task, participants likely form new episodic associations linking the cue word (e.g., *hive*) to any strong associates that come to mind (e.g., *bee*), as well as to the response they eventually generate. For example, if the cue on an unrelated trial is *hive*, a participant may initially think of the strong associate *bee* but eventually respond "chair." Rather than suppressing *bee*, the participant may instead episodically link *hive, bee*, and *chair* to each other. Under this assumption, when *bee* is presented during the word-naming task, it triggers retrieval of both *hive* and *chair* via these new episodic associations, and the time taken for this episodic retrieval to occur will slow naming. That is, new episodic associations may "block" access to the target word. Similar blocking accounts have been a key factor in nonsuppression interpretations of other paradigms often considered to show suppression (e.g., Raaijmakers & Jakab, 2013; Tomlinson, Huber, Rieth, & Davelaar, 2009). We took advantage of the fact that episodic retrieval should occur in both the related and the unrelated conditions to test the blocking account by computing separate blocking and suppression scores for each participant.

Specifically, an individual's RT in the unrelated condition reflects his or her baseline word-naming speed plus any effect of suppression plus any effect of blocking:

$$\text{unrelated RT} = \text{baseline RT} + \text{blocking} + \text{suppression}.$$

However, unlike suppression, which should occur only in the unrelated condition, blocking should occur in both the unrelated and the related conditions:

$$\text{related RT} = \text{baseline RT} + \text{blocking}.$$

Thus, we can create a suppression score as the simple difference between RTs in the unrelated and related conditions:

$$\text{suppression} = \text{unrelated RT} - \text{related RT}.$$

We can create an analogous blocking score as the RT difference between the related condition and the control condition (which should reflect baseline RT but neither blocking nor suppression):

$$\text{blocking} = \text{related RT} - \text{control RT}.$$

Note that although we have used difference scores for explanatory purposes, difference scores do not remove the between-individuals variability associated with the subtracted term, but rather reverse the sign of that variability. Therefore, the actual suppression and blocking scores used in the analyses reported here were residuals from regressions following the equations just given. Specifically, for the suppression score, we used residuals from the following regression:

$$\text{unrelated RT} = \beta_0 + \beta_1 \text{related RT}.$$

For the blocking score, we used residuals from a second regression:

$$\text{related RT} = \beta_0 + \beta_1 \text{control RT}.$$

We then used the suppression and blocking scores to test the blocking account of the slowing effect. Under the blocking account, slowing in the unrelated condition occurs because participants fail to control interference from the word-generation task during the word-naming task; thus, suppression scores should not correlate positively with performance on the OSpan task because the slowing reflects a failure of interference regulation. Under the suppression account, by contrast, slowing occurs because participants succeed in reducing interference by suppressing the activation of the strong associate; thus, individuals who have higher suppression scores should perform better on memory tasks that, like the OSpan task, require controlling interference.

To test the blocking account, we correlated OSpan scores with both suppression and blocking scores. As would be expected if the slowing effect reflects suppression, the correlation for suppression scores was positive, $r(50) = .33$, $p = .016$ (Fig. 1b). That is, higher suppression scores were associated with better OSpan scores. For

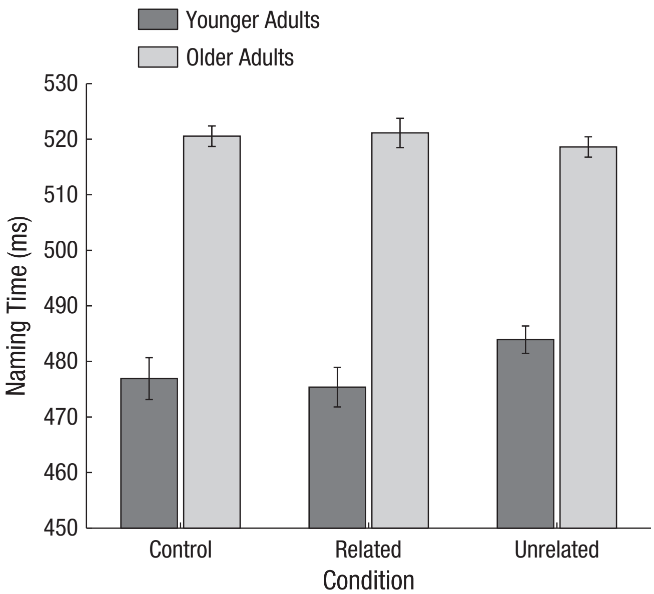

Fig. 2. Results from Experiment 2: younger and older adults' mean naming times in the three conditions. Error bars are 95% confidence intervals calculated using Masson and Loftus's (2003) method for within-subjects designs. Within an age group, means with nonoverlapping error bars are significantly different at the .05 level.

blocking scores, the correlation was negative, $r(50) = -.33$, $p = .016$. Inspection of the scatter plot in Figure 1c reveals a particularly influential observation in the lower right corner. When this observation was eliminated, the correlation remained negative but was no longer significant, $r(49) = -.24$, $p = .086$.[1] The fact that suppression and blocking scores have different patterns of correlation with memory performance, with greater suppression predicting better memory and blocking being uncorrelated with memory, indicates that the observed slowing cannot be attributed to blocking. (For a similar finding, see Aslan & Bäuml, 2011.) Therefore, Experiment 1 provides evidence that a single retrieval attempt is sufficient for younger adults to suppress competitors to below-baseline levels.

Experiment 2

In Experiment 2, we tested both young and older adults on the paradigm developed in Experiment 1. Testing younger adults provided the opportunity to potentially replicate the finding of below-baseline suppression. Testing older adults allowed us to achieve two additional goals. First, examining whether older adults show a slowing effect in the paradigm would provide an additional test of our suppression interpretation of the slowing effect observed in Experiment 1. If the slowing effect is due to interference during the word-naming task (e.g., blocking) rather than suppression, older adults should show more slowing than younger adults, given that older adults have an increased susceptibility to interference (Campbell et al., 2010; Gazzaley, Cooney, Rissman, & D'Esposito, 2005; Hasher & Zacks, 1988; Hulicka, 1967; Ikier & Hasher, 2006; Ikier et al., 2008; Kane & Hasher, 1995; Winocur & Moscovitch, 1983). Second, including older adults allowed for a direct test of the influential theory that suppression becomes impaired with age (Hasher et al., 2007; Hasher, Zacks, & May, 1999). If older adults have difficulty suppressing interfering information, they should show less slowing in the word-naming task than younger adults do.

Method

Seventy older adults (age range: 60–77 years, $M = 66.91$, $SD = 4.50$) and 38 younger adults (age range: 17–34 years, $M = 20.74$, $SD = 3.71$) participated. The older adults had an average of 16.8 ($SD = 3.44$) years of education and an average score of 36.84 ($SD = 2.50$) on the Shipley (1946) vocabulary test; the younger adults had an average of 14.04 ($SD = 1.70$) years of education and an average Shipley score of 31.42 ($SD = 3.87$). The age-related differences in both education and vocabulary were significant, as is common in the literature. All other aspects of the method and data screening were identical to the procedures in Experiment 1. On average, data trimming affected less than 1% of responses for younger adults and 2.6% of responses for older adults.

Results and discussion

As expected, there was a significant interaction between age and condition, $F(2, 212) = 3.30$, $p = .039$. As in Experiment 1, younger adults showed below-baseline suppression of associates from the unrelated trials; naming was slower for unrelated targets than for either control items or related targets (see the confidence intervals in Fig. 2). By contrast, older adults showed no evidence of suppression: There was no effect of condition among the older adults $F(2, 138) = 0.52$, $p = .59$ (Fig. 2). Pairwise comparisons confirmed that for older adults, RTs for unrelated targets did not differ from RTs for either control items or related targets, ts < 1. The finding of slowed competitor naming for younger but not older adults confirms a key prediction of the inhibitory theory of aging (Hasher et al., 2007) and strengthens the argument that the slowing effect exhibited by younger adults reflects suppression and not interference-based blocking.

General Discussion

Interference resolution is a critical factor in a healthy memory system. We have provided evidence that suppression facilitates interference resolution. When young adults rejected close associates of a cue, they suppressed those associates to below-baseline accessibility as measured by naming time. Further, young adults who showed stronger suppression performed better on a memory span task than did those who showed less suppression. By contrast, older adults showed no evidence of suppression.

These results demonstrate that a single retrieval attempt is sufficient for young adults to suppress competing information to below-baseline accessibility. Moreover, suppression occurs even when the competing information is never explicitly presented. This finding suggests that suppression of competitors may be a ubiquitous aspect of memory retrieval, at least for healthy young adults.

As noted, the results show that older adults do not suppress competitors during interference resolution. There is relatively little evidence linking older adults' difficulty resolving interference with impaired suppression abilities (but see Anderson, Reinholz, Kuhl, & Mayr, 2011; Healey, Hasher, & Campbell, 2013; Ortega, Gómez-Ariza, Román, & Bajo, 2012). Here we have provided direct evidence that older adults have impaired inhibitory mechanisms.

Author Contributions

M. K. Healey and L. Hasher designed the study. M. K. Healey and K. W. J. Ngo analyzed the data. M. K. Healey wrote the first draft of the manuscript, and all authors participated in the editing process.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Supplemental Material

Additional supporting information may be found at http://pss.sagepub.com/content/by/supplemental-data

Note

1. Our analysis of blocking scores started with the assumption that blocking actually occurs in this paradigm and tested whether it can account for the key slowing effect. However, it is not a forgone conclusion that blocking actually occurs. In fact, the blocking scores in Experiment 1 were not significantly different from zero, which suggests that minimal blocking occurred. The same was true of blocking scores for both younger and older adults in Experiment 2. Note that the fact that mean blocking scores were not different from zero does not compromise our analyses, as our regression framework relied on variability in blocking scores, not the mean level of those scores.

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