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Direct Evidence for the Role of Inhibition in Resolving Interference

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Abstract

Interference at retrieval is a major cause of memory failure. We tested the hypothesis that such interference is overcome by suppressing competing responses. In a three phase task, participants in the critical interference condition first performed a vowel-counting task that included pairs of orthographically similar words (e.g., ALLERGY and ANALOGY). After a delay, they solved word fragments (e.g., A _ L _ _ GY) that resembled both words in a pair but could only be completed by one. We then measured the consequence of having successfully resolved interference in Phase 2 by having participants read a list of words including the rejected competitors as quickly as possible. Interference condition participants were slower to name the competitors than were others in conditions that did not require interference resolution. These results constitute direct evidence for the role of active suppression in resolving interference at retrieval.

Direct Evidence for the Role of Inhibition in Resolving Interference

Interference between competing responses is perhaps the most common cause of memory failure (e.g., Keppel, 1968; Postman & Underwood, 1973; Watkins & Watkins, 1975). Nonetheless, identifying the mechanisms of interference resolution has proved extremely difficult and remains an area of active debate (e.g., Jonides & Nee, 2006). This paper provides direct evidence that resolving interference involves the suppression of competing responses.

Interference occurs when a retrieval cue (e.g., a cue in an experiment, a question in a conversation, a self generated thought) elicits multiple representations; to successfully recall the desired information, interference must be resolved. We (Hasher, Lustig, & Zacks, 2007; Hasher, Zacks, & May, 1999) and others (Bjork, 1989; M. C. Anderson & Spellman, 1995; Zanto & Gazzaley, 2009) have argued that resolution of interference entails the suppression of competing information. An alternative view is that facilitatory processes directly enhance the accessibility of target information (e.g., J. R. Anderson et al., 2004; J. R. Anderson & Reder, 1999). It has been difficult to discriminate between these alternatives because both inhibitory and facilitatory mechanisms predict similar outcomes; if either is successful, targets will be recalled (see MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003).

One distinguishing feature of suppression is that it acts not on targets but on competitors by making them *less* accessible, thus increasing the *relative* accessibility of target information. Therefore, a fingerprint of suppression should be reduced accessibility of competitors following interference resolution. We tested this prediction by having participants in the experimental condition resolve interference between targets and competitors and then measuring competitor accessibility.

The procedure, based on Ikier, Yang, and Hasher (2008), has 3 phases. Phase 1 creates the potential for interference (Figure 1, first column) by embedding pairs of orthographically similar words (e.g., ALLERGY and ANALOGY) in a vowel-counting task. Phase 2 encourages interference resolution by having participants solve word fragments that resemble both words in a pair (e.g., A _ L _ _ GY), but can actually be completed only by a target (ALLERGY) and not its competitor (ANALOGY). If the interference between target and competitor is resolved by suppressing the competitor, competitor accessibility should be reduced. Phase 3 tests for reduced competitor accessibility with a naming task. Naming time in this Interference condition is compared to several control conditions. In the No-Resolution condition (Figure 1, second column) targets and competitors are presented in Phase 1 but cannot complete any fragments in Phase 2, controlling for the possibility that it is the potential interference created in Phase 1 and not suppression during interference resolution that reduces competitor accessibility. In the No-Conflict condition (Figure 1, third column), competitors but not targets are presented in Phase 1, providing a measure of naming time in the absence of either potential interference or resolution. To preview, competitor naming was slower in the Interference condition than in either control condition, confirming that selection in the face of competition entails suppression.

Experiment 1

Method

Participants, Materials, and Procedure

141 introductory psychology students who were fluent English speakers since at least age 5 participated for course credit.

Phase 1: Encoding. Participants viewed 56 words including 15 targets and 15 competitors and reported aloud the number of vowels in each. Two lists of 15 target/competitor pairs were created. Targets and their competitors were the same length, began with the same letter, and on average shared 3.3 letters in corresponding positions (cf . *M* = 0.5 shared letters between targets and fillers). Orthographic similarity was minimized between non-paired words within and across lists.

Participants in the Interference and the No-Resolution conditions saw targets and matching competitors (half saw list 1 pairs and half saw list 2). Participants in the No-Conflict condition saw targets from one list and competitors from the other list.

Each word was shown for 1800 ms, with a 1000 ms ISI beginning with 3 buffer words followed by 15 competitors randomly mixed with 10 filler words, followed by 15 targets randomly mixed with 10 fillers, and ending with 3 buffer words. Filler words were similar in frequency and length to the targets/competitors but semantically and lexically dissimilar. A six-minute filler task (providing the missing digits in equations) followed Phase 1.

Phase 2: Retrieval. Participants were given 36 word fragments, including 15 critical fragments (e.g., A _ L _ _ GY) that could be completed by a target (e.g., ALLERGY) but not by the corresponding competitor (e.g., ANALOGY). In the Interference and No-Conflict conditions, but not in the No-Resolution condition, targets seen in Phase one could complete the critical fragments. Each fragment was shown for 4500 ms plus a 500 ms ISI and participants responded aloud. The task began and ended with 3 buffer fragments, followed by the 15 target fragments randomly mixed with 15 filler fragments.

In summary, Interference participants solved fragments for which they had seen the correct solution and an orthographically similar competitor; thus, correctly solving the fragments would require resolving interference between the two. No-resolution participants also saw targets and their competitors in phase 1, creating the potential for interference but none of the fragments in phase 2 required them to resolve that interference. No-Conflict participants solved fragments for which they had seen only the targets in phase 1 and thus should have experienced little target/competitor interference.

Phase 3: Naming. Participants read 33 words aloud as quickly as possible, each shown until a response was given and followed by a 1500 ms ISI. A voice key recorded RTs. The list began with 3 buffer words followed by the 15 competitors from Phase 1 mixed with 15 new words, which were roughly matched to the competitors in length and frequency. If Interference participants had suppressed the competitors during the fragment completion phase, those words should be less accessible and read more slowly than by either No-Resolution or No-Conflict participants, neither of whom resolved competition at retrieval.

A baseline condition was also included in which participants simply named the words in Phase 3 with no prior laboratory exposure to them.

Data analysis

Thirty-seven participants reported some awareness of connections among the phases of the study (as determined by a graded awareness questionnaire which progressed from general questions such as “did you notice any connection between the tasks” to specific questions such as “did you notice that some words repeated throughout the tasks?”) and were therefore eliminated from analyses.

We excluded any trial on which the participant failed to read a critical word or read it incorrectly (5.03% of observations). For participants in the Interference condition we considered only competitors for which they had correctly solved the corresponding fragment during Phase 2, as failure to solve the fragment could indicate that suppression was not successful, in which case competitor naming may not be slowed. To ensure stable competitor naming times, we excluded data from participants with fewer than 6 usable RTs (n = 4). Including these participants did not change the outcome of any significance test. The remaining 100 participants provided 6 to 13 usable RTs (average = 7.7).

Following recent statistical advice (Erceg-Hurn & Mirosevich, 2008), we winsorized (15%) naming RTs to correct for outliers and non-normal distributions. After winsorizing, a mean reaction time for each word type was calculated for each participant.

Results

Performance on the vowel counting task in Phase 1 was accurate (M = 93%, SEM = 0.01%) and did not differ as a function of word type (target versus competitor) $F(1, 75) = 1.62$, $p > .20$, or condition $F(2, 75) = 2.60$, $p > .08$. Confirming that exposure to targets and competitors during Phase 1 produced interference during Phase 2, Interference participants solved 8.04 (SEM = 0.27) critical fragments, reliably fewer than the 8.96 (SEM = 0.33) solved by No-Conflict participants, who saw only targets in Phase 1. The No-Resolution participants, who saw fragments unrelated to any words seen in Phase 1, solved 7.08 (SEM = 0.36) critical fragments, providing a baseline measure of fragment completion absent any exposure to the target. Both the Interference and No-Resolution participants preformed above this baseline, $t(48) = 2.13$, $p = .039$, and $t(50) = 3.87$, $p < .001$ respectively. That is, seeing a target in Phase 1 aids fragment completion, but having also seen the corresponding competitor creates interference, reducing the facilitative effect of having seen the target.

Table 1 shows the mean naming times for competitors and new words. There were no differences among the groups (Interference, No-Resolution, No-Conflict, and Baseline) in naming time for new words, $F(3, 96) < 1$. Competitor naming times indicate that resolving interference entailed suppressing competitors: Interference participants were slower to name competitors than No-Resolution and No-Conflict participants. Analyses of Covariance were run on competitor naming time with new word times as a covariate to control for between-subject variability in naming time[2]. Competitors were indeed named more slowly by Interference participants than by either No-Resolution participants, $F(1, 47) = 4.98$, $p = .03$, or No-Conflict participants, $F(1, 51) = 5.53$, $p = .02$, a finding consistent with suppression as the source of interference resolution.

By comparing naming time in the Baseline condition with the other conditions, it is possible to assess the strength of suppression. In all conditions except Baseline participants had seen the competitor in Phase 1 before naming it in Phase 3, therefore absent any suppression their naming of competitors should be speeded relative to baseline. Both No-Resolution, $F(1, 43) = 9.92$, $p < .01$, and No-Conflict participants $F(1, 47) = 8.30$, $p < .01$, showed such a priming effect. Interference participants, however, showed no priming, $F(1, 45) = < 1$. Thus, the suppression applied during interference resolution was sufficiently strong to return competitor accessibility to baseline, making it as if the Interference participants had never seen competitors before Phase 3.

Experiment 2

Is there an alternative interpretation of slowed competitor naming in the Interference condition? One suggestion is that the association between target and competitor is strengthened during fragment completion. Thus, when a competitor is presented for naming in Phase 3, it triggers retrieval of both the competitor *and* the target, slowing naming. A strong test of the association strengthening account is to measure the priming of *targets* in the Interference condition relative to baseline: if association strengthening produced the slowing of competitors then targets should also show a slowing effect. By contrast, no slowing of targets would be expected under a suppression explanation. Therefore, we tested 56 new participants (using the same selection criteria as above) in the Interference and Baseline conditions with participants now naming targets instead of competitors in the final phase. Except for this change in Phase 3, all other procedures including data screening and trimming procedures, remained the same as in Experiment 1.

Results

Naming time for targets showed facilitation relative to baseline (Table 2), $F(1, 53) = 18.83$, $p < .001$. This finding is inconsistent with an association strengthening account of the competitor slowing seen in Experiment 1, suggesting that competing information is indeed suppressed during interference resolution[3].

These data also allow us to address an additional question; does resolving conflict entail facilitating targets, in addition to suppressing competitors (see e.g., Norman, Newman, & Detre, 2007)? If facilitation does play a role in resolution, then successfully resolving interference should produce *increased* priming of targets just as it produces decreased priming of competitors. To test for increased target priming, we compared the amount of priming for targets in the Interference condition, which should reflect priming due to pre-exposure during phase 1 plus any facilitation due to competition resolution, with the amount of competitor priming in the No-Conflict condition, which reflects only priming due to pre-exposure. Targets in the Interference condition showed 42ms of priming (Baseline target naming time – Interference target naming time); no more than the 46ms shown by competitors in the No-Conflict condition (Baseline competitor naming time – No-Conflict competitor naming time) [4]. As a more rigorous test we conducted an 2X2 ANCOVA with baseline versus priming condition as one factor and target versus competitor as the other factor and new word naming time as a covariate. If the interference resolution increased the amount of priming for targets, such an ANOVA should produce a significant interaction: it did not $F(1, 101) = 0.07$, $p > .70$.

Discussion

Direct evidence for the operation of inhibitory mechanisms at behavioral levels has been notoriously difficult to find (e.g., Macleod et al., 2003). Here we looked for a fingerprint of inhibition by assessing the consequences of competition at retrieval for the rejected competitor. We provide strong, direct evidence for inhibitory mechanisms: Participants who successfully resolved interference between competing words were subsequently slower to name the rejected word than participants who experienced no interference.

This study is not the first to show that retrieving one piece of information has negative consequences for related information; post-retrieval deficits have been shown with a variety of paradigms such as retrieving versus re-reading recently presented information (Higgins & Johnson, 2009), fan effect studies (Radvansky, Zacks, & Hasher, 2005), category-stem completion (Blaxton & Neely, 1983), and the retrieval induced forgetting (RIF) paradigm (M. C. Anderson, Bjork, & Bjork, 1994; M. C. Anderson & Spellman, 1995). However, many researchers argue that these effects are best explained by mechanisms other than suppression (e.g., Higgins & Johnson, 2009; Macleod et al., 2003; Gorfein & Brown, 2007). Perhaps the best evidence for suppression comes from the RIF paradigm, in which participants learn lists of category-exemplar pairs and then practice retrieving a subset of those exemplars. The practice impairs subsequent retrieval of the unpracticed exemplars. However, there have been reports of difficulty replicating some of the key findings supporting inhibitory explanations of RIF (Williams & Zacks, 2001) and several authors have proposed non-inhibitory accounts (Williams & Zacks, 2001; Macleod et al., 2003). One way to adjudicate between inhibitory and non-inhibitory accounts in general, however, is to search for converging evidence from different paradigms; the present study provides such evidence.

The present data expand our understanding of suppression effects in a number of ways. First they show that suppression occurs even in implicit tasks in which participants are not explicitly asked to retrieve a subset of previously learned information. Some RIF studies have used implicit tasks to test for suppression after explicit retrieval practice (e.g., Perfect, Moulin, Conway, & Perry, 2002; Bajo, Gómez-Ariza, Fernandez, & Marful, 2006). However, in the present study all phases, including encoding and retrieval, are implicit. Implicit situations probably more closely simulate the occurrence and resolution of interference outside the laboratory. Secondly, the present findings show that suppression can occur even after a single retrieval episode whereas most other studies involve multiple retrieval attempts (though retrieval need not be successful; Storm & Nestojko, in press) with a single episode often producing no suppression (Shivide & Anderson, 2001) or even facilitation (Blaxton & Neely, 1983). Finally, the present study provides information about the magnitude of suppression effects, showing that interference resolution returns competing information to a baseline level of accessibility but no lower. In the present study, there was no evidence of heightened activation for targets, consistent with the view that the outcome of successful resolution of competition at retrieval is a heightening in the relative, not absolute accessibility of the target.

We note that effects similar to the suppression found here may occur in a variety of tasks, including complex working memory span tasks, which are laden with interference according to some views (e.g., Lustig, May & Hasher, 2001) and that require retrieval from long-term memory according to other views (e.g., Healey & Miyake, 2009; Unsworth & Engle, 2007). The present data are also relevant to neuroimaging findings that implicate the left inferior frontal gyrus (IFG) in interference resolution processes (Nelson, Reuter-Lorenz, Persson, Sylvester, & Jonides, 2009; Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997). Based on this literature we would predict that individuals showing the greatest IFG activity during interference resolution should show the greatest slowing effect during a naming task. As well, it is possible that the ability to ignore distraction at encoding (Vogel, McCollough, & Machizawa, 2005) is related to the inhibitory mechanism that enables resolution of competition at retrieval.

Classic interference theory (Postman & Underwood, 1973) posited that memory failures were largely due to competition between traces at retrieval. This view of the centrality of interference has greatly influenced contemporary research, yet the critical question of how interference is resolved has remained open and contested. The data reported here provide some of the strongest evidence to date that retrieval of one trace entails suppression of its competitors, reducing their accessibility to the level of semantic memory baselines. We suggest that the logic of looking for the fingerprints of inhibition not in what happens to target information but in what happens to competing information holds great promise for both behavioral and neuroimaging work.

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Footnotes

[1]The pattern of results was qualitatively identical for untrimmed data and when aware participants were included.

[2]New word naming was included as a covariate in all RT analyses and was always a significant covariate.

[3]Norms from the English Lexicon Project (Balota et al., 2007) confirm that the difference in baseline naming speed between targets and competitors is not limited to the current study. This difference does not impact our interpretation of the findings.

[4]Had targets been strengthened during competition resolution, one could argue that slowed competitor naming in Experiment 1 was due to interference from the strengthened targets. The finding that targets showed no additional facilitation as a result of competition resolution speaks against such an account.

Table 1

Mean (SEM) reaction times on the naming task in milliseconds by condition and word type

	Group			
Word Type	Interference *n* = 26	No-Resolution *n* = 24	No-Conflict *n* = 28	Baseline *n* = 22
Competitor	610 (15.7)	577 (15.8)	569 (15.8)	615 (17.7)
New	576 (13.2)	567 (13.6)	563 (14.3)	576 (15.1)

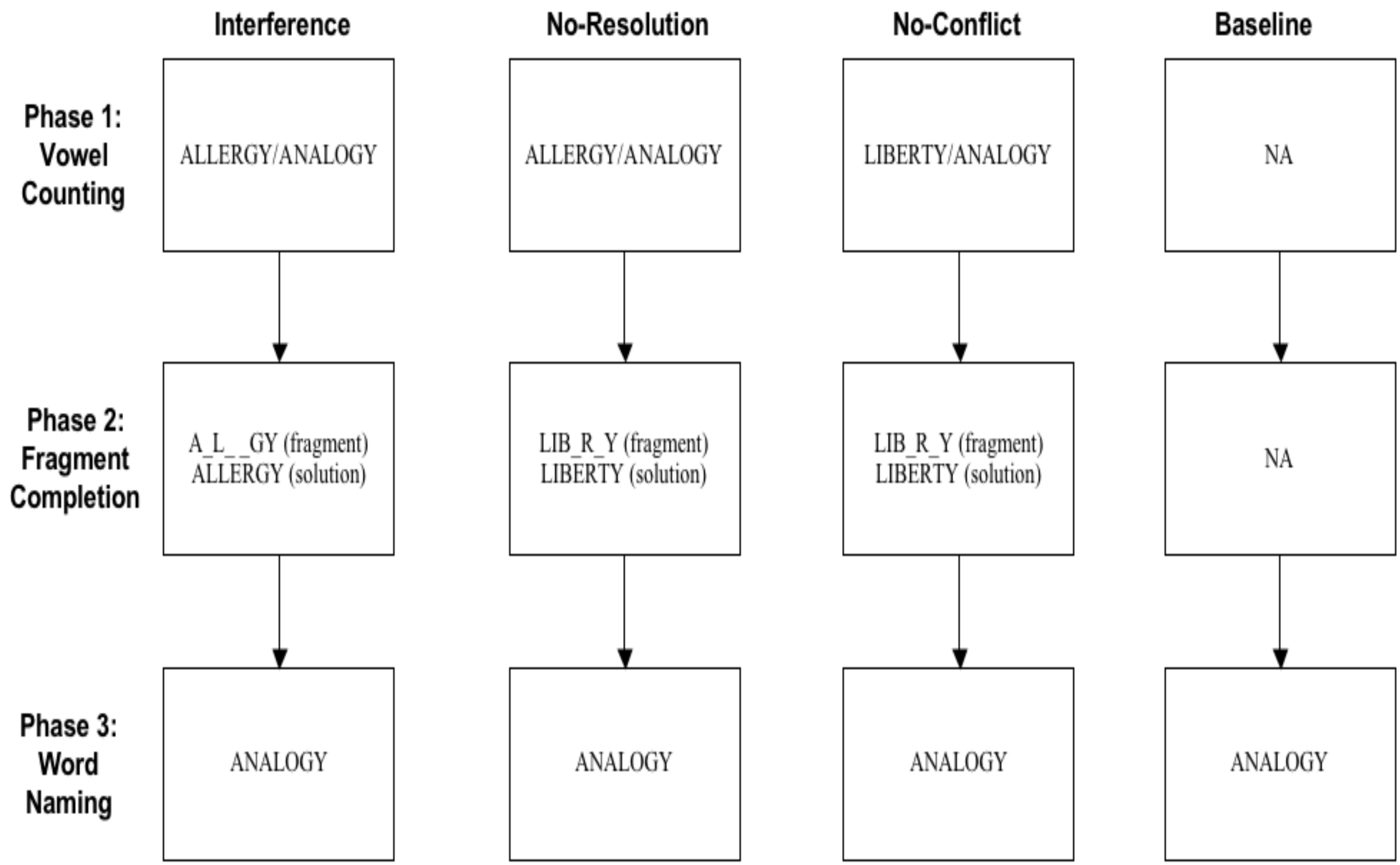
Table 2

Mean (SEM) reaction times on the naming task in milliseconds by condition and word type

	Group	
	Interference	Baseline
Word Type	*n* = 30	*n* = 26
Target	506 (13.7)	548 (17.6)
New	543 (18.5)	547 (18.9)

Figure Caption

Figure 1. Illustration of the sequence of events in each condition. The top row shows examples of the target/competitor pairs seen in Phase 1. The second row shows examples of the fragments solved in Phase 2 along with their solutions. The last row shows examples of the competitors named in Phase 3.


Interference
No-Resolution
No-Conflict
Baseline
Phase 1: Vowel Counting
ALLERGY/ANALOGY
ALLERGY/ANALOGY
LIBERTY/ANALOGY
NA
Phase 2: Fragment Completion
A_L_ _GY (fragment)
ALLERGY (solution)
LIB_R_Y (fragment)
LIBERTY (solution)
LIB_R_Y (fragment)
LIBERTY (solution)
NA
Phase 3: Word Naming
ANALOGY
ANALOGY
ANALOGY
ANALOGY