

The Role of Suppression in Resolving Interference: Evidence for an Age-Related Deficit

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Abstract

Difficulty with memory retrieval is a salient feature of cognitive aging and may be related to a reduction in the ability to suppress items that compete for retrieval. To test this hypothesis directly, we presented a series of words for shallow coding that included pairs of orthographically similar words (e.g., ALLERGY and ANALOGY). After a delay, participants solved word fragments (e.g., A _ L _ _ GY) that resembled both words in a pair but could only be completed by one. We measured the consequence of having successfully resolved competition by having participants read a list of words including the rejected competitors as quickly as possible. Response time was compared to control conditions that did not require resolving competition. Older adults showed no evidence of suppression; instead they showed priming for the competitors, in sharp contrast to strong suppression effects previously observed in younger adults. Whereas previous studies have provided indirect evidence for suppression deficits by examining the ability to produce *targets* in high interference situations, here we provide direct evidence for a suppression deficit by examining the accessibility of rejected *competitors*.

The Role of Suppression in Resolving Interference:

Evidence For an Age Related-Deficit

Difficulty remembering is one of the most salient features of cognitive aging (Balota, Dolan, & Ducheck, 2000; Grady & Craik, 2000; Hasher & Zacks, 2006; Light, 1991; Lindenberger & Ghisletta, 2009) and understanding the source of these difficulties is a key goal of both basic and applied research. For young adults, memory failure is often caused by interference between competing memories (J. R. Anderson & Bower, 1974; Postman & Underwood, 1973; Radvansky, 1999a; 1999b; Underwood, 1957; Underwood & Postman, 1960). Indeed, interference between competing response tendencies is a cause of cognitive failures in many domains including language processing (Thompson-Schill et al., 2002) and attention (Mayr, 2002). The inability to resolve interference has also been linked to a variety of developmental disorders (Lindenberger, 2008; Nigg, 2000) as well as to individual differences in fluid intelligence (Burgess, Gray, Conway, & Braver, 2011; Hasher, Lustig, & Zacks, 2007). It is therefore not surprising that interference has an even greater negative impact on older adults, suggesting that an inability to resolve interference underlies age related memory impairments (Campbell, Hasher, & Thomas, 2010; Hasher & Zacks, 1988; Hulicka, 1967; Ikier & Hasher, 2006; Ikier, Yang, & Hasher, 2008; Kane, 2002; Logan & Balota, 2003; Winocur & Moscovitch, 1983; Radvansky, Zacks, & Hasher, 2005). The question is: Why do older adults have trouble resolving interference?

Many researchers have proposed that ability to suppress competing memories, a key interference resolution mechanism in young adults (M. C. Anderson & Spellman,

1995; Bäuml, Pastötter, & Hanslmayr, 2010; Healey, Campbell, Hasher, & Ossher, 2010; Norman, Newman, & Detre, 2007; Storm, Bjork, & Bjork, 2007), becomes impaired with age (Hasher et al., 2007; Hasher & Zacks, 1988; Ikier et al., 2008; Ikier & Hasher, 2006). We directly address the issue of whether or not there is a suppression deficit in older adults using a 3-phase task that has provided dramatic evidence of suppression during interference resolution by younger adults (Healey et al., 2010).

In the interference condition, the potential for interference is created in Phase 1 (Figure 1, column B) by presenting a word list that includes pairs of orthographically similar words (e.g., allergy and analogy) under the cover of a vowel counting task. Phase 2 creates competition between candidates by presenting a series of fragments for completion, some of which resemble both words in a pair (e.g., a _ l _ _ gy), but that can only be completed by a target word (e.g., allergy) and not by its competitor (e.g., analogy). Phase 3 tested for suppression by measuring how accessible the competitors (e.g., analogy) are after interference resolution using a speeded naming task, which required participants to read a list of words, including the critical competitors, as quickly as possible.

Healey et al. (2010) provided evidence for suppression in young adults by comparing the Phase 3 naming times of competitor words (e.g., analogy) with naming times in several control conditions that did not require resolving interference in Phase 2. In the no-resolution condition (Figure 1, column C), both target and competitor words (e.g., allergy/analogy) are presented in Phase 1, creating the potential for interference, but neither word can be used to complete any word fragments in Phase 2. Thus, the Phase 3 data from the no-resolution condition provides a measure of naming time (or priming)

when the potential for interference is created during Phase 1, but never resolved in Phase 2. In the no-conflict condition (Figure 1, column D), Phase 1 presents competitor words (e.g., analogy) but not the corresponding targets (e.g., liberty is presented instead of allergy), providing a measure of priming of the critical competitor word (e.g., analogy) in the absence of either potential interference at encoding or conflict resolution at retrieval during fragment completion. In the baseline condition, participants merely read the words of Phase 3 with no prior exposure to them. Evidence of suppression by young adults was reported in Healey et al. and can be seen in Figure 2: By contrast with the two control conditions (no-resolution and no-conflict), both of which showed priming of the competitor relative to baseline (Healey et al., 2010), words in the interference condition showed no priming. For young adults, resolving interference entailed suppressing the accessibility of the competitor words to a pre-exposure baseline.

Here we use the same paradigm and materials to assess the suppression abilities of older adults. If older adults are able to suppress competitors, the pattern of naming times in Phase 3 should be similar to the pattern previously reported for younger adults. By contrast, if older adults do indeed suffer from a suppression deficit, unlike young adults, they should show priming for competitor words in the critical interference condition.

Method

Participants

Data from 136 older adults are reported. Older adults were residents of the Toronto area and received monetary compensation. Demographic information for both

the older adults used in the present analyses and the Healey et al. (2010) younger adult sample is presented in Table 1. The older adults had significantly more years of education, $t(231) = 8.23$, $p < .01$, and higher vocabulary scores, $t(231) = 13.62$, $p < .01$, than younger adults. There were no significant effects of condition or condition X age group interactions for any of the demographic variables in table 1 (all $p > .1$). Participants were randomly assigned to the conditions outlined in Figure 1.

Materials and procedure

The materials and procedure used with the older adult sample were identical in all respects to those used for the younger adult sample in Healey et al. (2010). For the sake of completeness, we include full details here.

Phase 1: Encoding. Participants viewed 56 words and reported aloud the number of vowels in each. In the interference and the no-resolution conditions, the list included 15 target words and 15 competing words. Two lists of target-competitor pairs were created, each consisting of 15 pairs. Participants in the no-conflict condition were shown targets from one list and competitors from the other list (e.g., rather than allergy/analogy, a no-conflict target/competitor pair would be liberty/analogy, see Figure 1 column D). In these three conditions, items were presented in the following sequence: 3 buffer words, followed by 15 competitor words randomly mixed with 10 filler words, then 15 target words randomly mixed with 10 fillers, and finally 3 buffer words. Words were presented for 1,800 ms, followed by a 1,000-ms interstimulus interval (ISI). Following Phase 1 there was a 6-min nonverbal filler task. Target words and competitor words were equated for length and log frequency (using Hyperspace Analogue to Language frequency norms;

Lund & Burgess, 1996), t 's < 1, for both length (target mean = 7.14 words; competitor mean = 7.14 words) and frequency (target mean = 8.18; competitor mean = 7.85).

Phase 2: Fragment completion. Participants attempted to solve 36 word fragments including 15 critical fragments (e.g., a_l_ _gy) that could be completed only by a target word (e.g., allergy). In the interference and no-conflict conditions, the target words seen in Phase 1 could be used to complete the fragments. In the no-resolution condition the fragments could not be completed with a previously seen word. Fragments were presented for 4,500 ms with a 500-ms ISI. Participants responded aloud. The 15 target-word fragments were presented with 15 randomly interspersed filler fragments. Three buffer fragments were presented both at the beginning and end of the task. Participants were given no feedback on their accuracy in completing the fragments.

To summarize, in the interference condition, participants solved word fragments for which they had seen both the correct solution and an orthographically similar competitor. In the no-resolution condition participants also saw targets and their competitors in Phase 1, creating the potential for interference, but none of the word fragments in Phase 2 required participants to resolve that interference. In the no-conflict condition, participants solved word fragments for which they had seen only target words in Phase 1, and thus should have experienced little target-competitor interference.

Phase 3: Naming. Participants read 33 words aloud as quickly as possible. The list included the competitor item (e.g., analogy) of each pair that had been primed in Phase 1 (compare the first and third rows in Figure 1). Words were presented one at a time and remained on screen until a response was given. A 1,500-ms ISI separated word presentations. This list began with 3 buffer words, followed by the 15 critical words

mixed with 15 new words. Filler words were similar in frequency and length to the words in the orthographically similar pairs, but semantically and lexically dissimilar. Reaction times were measured with a voice key.

Baseline Condition. Baseline participants completed only the Phase 3 word-naming task, without completing Phases 1 or 2, providing a measure of baseline naming speed for the critical words.

To facilitate comparison with Healey et al., we report analyses of data from participants who were unaware of the connections between phases of the study. We stress, however, that including aware older adults does not change the outcome of any significance test in the naming time analyses reported below. Awareness was determined by a series of questions, which progressed from general (e.g., “Did you notice any connection between the tasks?”) to specific (e.g., “Did you notice that some words repeated throughout the tasks?”).

Data Screening

We followed the data processing procedure of Healey et al. (2010). Naming trials on which the participant failed to read a critical word or read it incorrectly were excluded from analysis. For the interference condition, only competitors for which the participant had correctly solved the corresponding word fragment during Phase 2 were included in the analyses. Data from participants with fewer than 6 usable trials were excluded to ensure reliable estimates of RT. Table 2 shows the exclusion rates across conditions by exclusion criterion. The distribution of exclusions across conditions for older adults was similar to that found for the Healey et al. (2010) younger adult sample (i.e., 32 in the interference condition, 4 in the no-resolution condition, and 4 in the no-conflict

condition). The sample size and demographic information provided above is based only on included participants.

To reduce the influence of extreme observations, naming times for critical items were winsorized by 15% within condition. Winsorizing is an increasingly common procedure (e.g., Erceg-Hurn & Mirosevich, 2008; Nee & Jonides, 2009; Van Dyke & McElree, 2011), which reduces the influence of extreme values and ensures any mean differences represent differences in the body of the distributions, not the tails. Healey et al. (2010) used the same trimming procedure but with a highly conservative 5% Winsorizing. Using a 5% trim on the older adult data does not change the qualitative pattern of results but adds variability due to a larger number of extremely slow responses by older adults compared with younger adults making the effects difficult to detect statistically. Therefore, a 15% winsorization was used for the older adult data and we reanalyzed the younger adult data with the same 15% winsorization (which does not change the pattern of results reported by Healey et al. but does lead to slightly different means as reported here in Figure 2). We note that even 15% winsorization is more conservative than the 20% recommended by some statisticians (Erceg-Hurn & Mirosevich, 2008).

Analyses of covariance (ANCOVAs) were carried out on competitor naming times, with new-word naming times (i.e., filler words from the Phase 3 naming list) as the covariate to control for between-subjects variability in naming time. Table 1 shows the mean reaction times for the new words.

Results

Manipulation Check

To establish that older adults fail to suppress when resolving interference, we first establish that they did indeed experience interference when solving the fragments. An indirect measure of interference is the number of fragments correctly completed in the no-conflict condition (in which participants saw the solution to critical fragments in Phase 1; Figure 1 column D) versus the interference condition (in which participants saw both the correct solution and the competitor in Phase 1, Figure 1 column B). Surprisingly, however, completion rates (Figure 3A) did not differ between these two conditions for older adults, $t(71) < 1$.

As a more direct measure of interference, we counted how often participants used the orthographically related competitors to (inaccurately) complete fragments (Figure 3B). The Phase 2 row of Figure 1 shows examples of the competitors for each condition (note that only in the interference condition are these competitors actually primed in Phase 1). Confirming that older adults are highly susceptible to interference, they had higher competitor intrusion rates than younger adults even in the no-conflict condition, $t(60) = 3.88, p < .001$, and the no-resolution condition, $t(60) = 5.17, p < .001$, in which the competitors are not explicitly presented during the experiment. In the interference condition, older and younger adults experienced similar levels of interference, $t(63) = 0.53$. That is, whereas younger adults only experienced interference if the competitors were primed, older adults always experienced interference from the competitors. Comparing interference levels across conditions bolsters this interpretation: For younger

adults the intrusion rate was not different from zero in either the no-resolution or no-conflict condition ($t's < 1$), but in the interference condition the intrusion rate was significantly higher than in either control condition ($t's > 8.8$). By contrast, older adults in the interference condition had somewhat higher competitor intrusion rates than older adults in the no-conflict condition, $t(71) = 2.75$ $p < .01$, but not in the no-resolution condition, $t(75) = 0.60$. Using a related paradigm, Logan and Balota (2003) also found that older, but not younger adults, experienced interference from competitors that were never explicitly presented (see also Hamm & Hasher, 1992).

We return to the fragment completion results in the discussion. However, for present purposes, the critical finding is that older adults experienced strong interference in the fragment completion phase. We turn now to the central question of the paper: do older adults suppress competitors when resolving the interference during fragment completion?

Naming time Analyses

Naming time data from older adults for the critical words are shown in (Figure 2); the following analyses control for individual differences in new word naming time (Table 1). In the no-resolution and no-conflict conditions older adults saw the competitor words during Phase 1 but had no need to suppress them during the Phase 2 fragment task, leading to priming (i.e., faster naming times relative to the baseline condition) in Phase 3 for both the no-resolution, $F(1, 59) = 14.5$, $p < .001$, $\eta_p^2 = .20$, and no-conflict, $F(1, 55) = 10.98$, $p < .002$, $\eta_p^2 = .17$, conditions. Older adults in the interference condition also saw the competitors during Phase 1 but rejected them during interference resolution in Phase

2. If older adults had used suppression to resolve the interference, they should show reduced or absent priming for competitors. However, older adults showed no evidence of suppression: competitor naming was significantly faster in the interference condition relative to baseline, $F(1, 60) = 30.03, p < .001, \eta_p^2 = .33$. In fact, rather than showing suppression, older adults were actually faster to name the critical words in the interference condition than in either the no-conflict, $F(1, 69) = 5.46, p < .05, \eta_p^2 = .07$, or the no-resolution conditions, $F(1, 73) = 3.75, p < .06, \eta_p^2 = .05$.

By contrast, the younger adults in Healey et al. (2010) showed clear evidence of suppression: As can be seen in Figure 2, priming was completely eliminated in the interference condition, indicating that competitors had been suppressed back to baseline accessibility during interference resolution. An ANOVA on the combined older and younger adult data confirmed what is clear from Figure 2: condition interacted significantly with age group, $F(3, 228) = 4.53, p < .05, \eta_p^2 = .07$. Considering only the interference and baseline conditions there was a significant age X condition interaction, $F(1, 111) = 7.70, p < .01, \eta_p^2 = .07$, indicating that younger adults showed a greater suppression effect. There was, however, no age interaction when considering only the control conditions and baseline, $F(2, 170) = 1.13, p = .33$, indicating a lack of age difference in priming for non-suppressed words. Including education and vocabulary scores as covariates does not change the pattern of age X condition interactions.

Discussion

These data demonstrate a critical difference in how younger and older adults resolve interference: Younger adults suppress competitors during interference resolution; older adults do not. This inability to suppress may illuminate one of the most important questions in cognitive aging research: why older adults have difficulty retrieving information from memory

If older adults do have a suppression impairment, competitors should be more available to them than they are to younger adults. And that is exactly what we find: older adults name the competitors more quickly than do the younger adults in Phase 3. Some readers may wonder why this difference in accessibility was not detected by the fragment completion task (either in the number of correct completion or in intrusion rates). The most likely answer is that naming time is simply a much more sensitive measure than intrusion rates. Small differences in accessibility may translate to RT differences without leading to differences in number of overt intrusions.

While the present paradigm is implicit in the sense that participants are not instructed to use information from Phase 1 when solving fragments in Phase 2, the implications are not limited to implicit tasks. First, the same pattern of results was obtained when we included in our analyses participants who were explicitly aware of the connection between phases of the experiment. Second, both explicit and implicit memory tests are vulnerable to interference and show parallel age effects (Ikier et al., 2008; Ikier & Hasher, 2006; Lustig & Hasher, 2001a, 2001b). Episodic recall reflects both explicit and implicit influences (cf. Jacoby, 1991), and neuroimaging data also suggest considerable overlap between implicit and explicit systems (e.g., Hannula & Greene,

2012). Therefore, the current finding of impaired suppression may help explain age differences in explicit recall of episodic details.

Whereas most theories attribute memory deficits to either impairments in encoding mechanisms (e.g., Gazzaley et al., 2008; Naveh-Benjamin, 2000) or retrieval mechanisms (e.g., Cohn, Emrich, & Moscovitch, 2008), an inhibitory theory suggests that both encoding and retrieval are disrupted by suppression deficits. Failing to suppress will clearly impair interference resolution at retrieval, however suppression deficits will also have consequences at encoding (Hasher & Zacks, 1988). When a stimulus is presented during the encoding phase of a memory task it will automatically activate a cascade of associated thoughts and memories (J. R. Anderson et al., 2004). Younger adults are likely to use suppression to prune this cascade to a smaller number of contextually appropriate memories. But for older adults, these irrelevant thoughts and memories will remain active, allowing them to become bound to relevant information in memory (see e.g., Hamm & Hasher, 1992). As a result, the memories of older adults will likely be more densely interconnected than those of young adults, setting the stage for massive interference at retrieval (Radvansky, Zacks, & Hasher, 2005). That is, impaired suppression both creates the potential for massive interference, by allowing indiscriminate binding at encoding, and undermines the ability to resolve that interference, by preventing suppression of competitors at retrieval. This suggestion fits well with evidence that older adults form associations between unrelated aspects of an episode (Campbell et al., 2010; Naveh-Benjamin, 2000) and fail to constrain retrieval to contextually appropriate sources (Healey, Campbell, & Hasher, 2008; Jacoby, Bishara, Hessels, & Toth, 2005a; Jacoby, Shimizu, Velanova, & Rhodes, 2005b).

Logan and Balota (2003) have also reported that older adults experience more interference than younger adults from competitors in fragment completion. A close comparison of the two sets of findings reveals an interesting difference. Whereas we found no age differences in interference from primed competitors (i.e., in the interference condition), Logan and Balota (Experiments 1 & 2) found that older adults were more likely than younger adults to intrude even primed competitors. This apparent discrepancy may be due to differences in the time between competitor priming and fragment completion (250ms in their study versus several min in the present study) or to the number of items that intervene between presentation and test (0 in their study, many in ours). While there is clearly room for additional work on mediating variables, both studies demonstrate that older adults have difficulty dealing with interference. The present results take the critical next step of examining the accessibility of the competitors after they have been rejected, demonstrating that older adults continue to have easy access to these items while young adults do not: Older adults fail to suppress the competitors, whereas younger adults do suppress.

Other studies have found that older adults retain access to information once it is no longer task relevant (for a review see Healey et al. 2009), however, these studies have not directly addressed the mechanism responsible for such persistent access. In particular these earlier studies lacked the No-Resolution control condition of the present study, which allows us to rule out non-suppression accounts of the age difference in slowing (e.g., MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003; Tomlinson, Huber, Rieth, & Davelaar, 2009). Recent work with the retrieval practice (Ortega, Gómez-Ariza, Román,

& Bajo, 2012) and the think/no-think (M. C. Anderson, Reinholz, Kuhl, & Mayr, 2011) paradigms has also provided evidence that older adults fail to suppress competitors during memory retrieval. However, both paradigms have been the subject of controversy in the literature, with reports of non-replications (Bulevich, Roediger, Balota, & Butler, 2006; Williams & Zacks, 2001) amidst reports of replications (for a review see Storm & Levy, 2012), apparent failures of key predictions (Jakab & Raaijmakers, 2009; Raaijmakers & Jakab, 2011), and alternative, non-inhibitory, accounts (MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003; Tomlinson, Huber, Rieth, & Davelaar, 2009). The present results may help to circumvent these issues by using a very different paradigm, with a highly sensitive reaction time-based measure of suppression to provide converging evidence of suppression by younger adults and impaired suppression in older adults.

If older adults fail to suppress, how *do* they resolve interference? One possibility is that older adults rely on a deliberate post-retrieval checking procedure that does not require inhibition, similar to the “recall-to-reject” (Gallo, Bell, Beier, & Schacter, 2006) and generate/recognize (Bahrick, 1970) notions of memory monitoring. On the fragment completion task used here, older adults may generate a candidate response, check if it fits the fragment, and produce it only if it fits. Such a strategy would only be effective on tasks that provide a clear criterion, such as a word fragment, against which to check candidate responses. This suggestion is consistent with evidence that older adults tend to be most impaired on memory tests that provide few external cues, such as free recall, and show better performance on tests such as recognition and cued recall that provide strong cues (Craig, 1994; Craig & McDowd, 1987). Recently developed procedures for detecting strategy differences among younger adults (Healey & Kahana, 2013) may prove

useful in determining if older and younger adults do indeed employ different interference resolution strategies.

Conclusion

There is considerable evidence that older adults have particular difficulty on tasks that involve distraction or interference (Campbell et al., 2010; Healey et al., 2008) and that this susceptibility contributes to age-related memory deficits (Gazzaley, Cooney, Rissman, & D'Esposito, 2005; May, Hasher, & Kane, 1999; Rowe, Hasher, & Turcotte, 2008). There is less evidence, however, of an age-related deficit specifically in inhibition of competitors. Here we provide direct evidence that older adults have impaired inhibitory mechanisms by showing that, unlike younger adults, older adults do not suppress competitors during interference resolution.

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Table 1: Demographic information and mean reaction times (in milliseconds) for new words (i.e., filler words) in the Phase 3 Naming Task. Values in parentheses are standard deviations.

	Condition			
	Baseline	Interference	No-Resolution	No-Conflict
Older				
Initial <i>n</i>	25	88	45	39
<i>n</i> after awareness				
exclusions	25	47	38	34
<i>n</i> after valid trial				
exclusions	25	39	38	34
Age	67.7 (4.7)	69.2 (04.2)	67.9 (5.3)	69.1 (5.4)
Years Education	17.2 (3.4)	17.2 (3.8)	15.9 (2.7)	16.0 (4.2)
Vocabulary	37.0 (2.3)	35.8 (3.1)	36.4 (2.6)	35.8 (3.0)
	595			
New Word RT	(71.4)	548 (55.6)	568 (62.6)	590 (71.5)
Younger				
Initial <i>n</i>	22	58	28	32

<i>n</i> after awareness				
exclusions	22	26	24	28
<i>n</i> after valid trial				
exclusions	22	26	24	28
Age	19.7 (1.9)	19.7 (2.0)	19.4 (1.3)	19.0 (1.6)
Years Education	13.6 (1.8)	13.4 (1.6)	13.6 (1.5)	13.1 (1.5)
Vocabulary	31.2 (3.6)	29.5 (3.8)	30.5 (3.5)	30.9 (3.1)
	570			
New Word RT	(52.0)	567 (50.2)	561 (62.6)	552 (56.7)

Note: For comparison purposes with Healey et al. (2010), we excluded any participants who were aware of connections between the phases. In a second step we excluded any participants with too few valid trials. As noted in the text, including aware participants does not change the outcome of the naming time analyses. See the text for details on these exclusion criteria. The awareness criterion does not apply to baseline participants as they completed only Phase 3 and could not be aware of connections between phases. Vocabulary scores are from the Shipley (1946) test. Education information was missing for 3 participants and vocabulary information was missing for 3 participants.

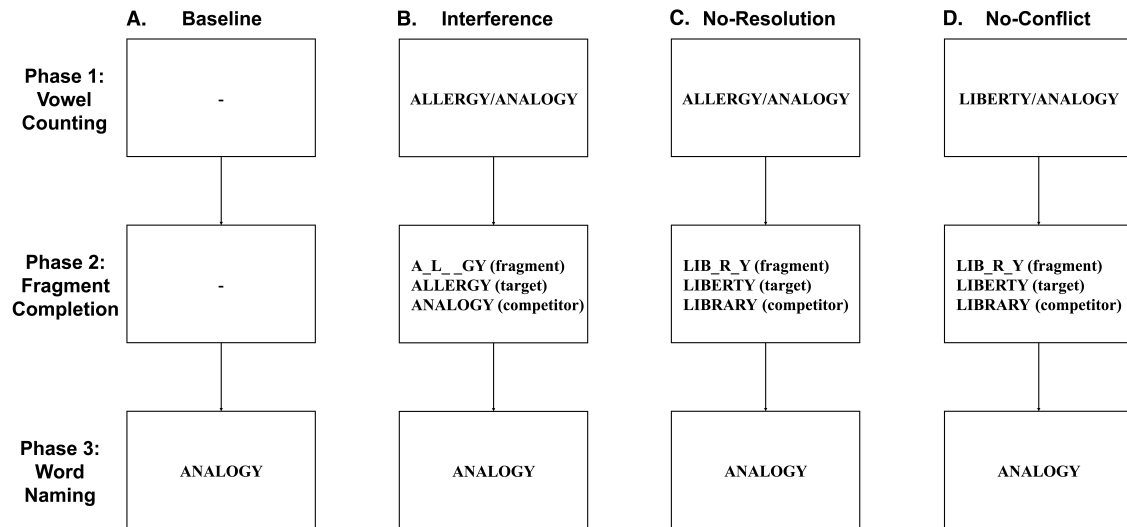


Figure 1. Comparison of the sequence of events in the four conditions (interference, no-resolution, no-conflict, and baseline). The top row shows examples of target-competitor pairs presented in Phase 1. The middle row shows examples of the word fragments to be solved in Phase 2, along with their intended solutions (targets), and competitors. The bottom row shows examples of the critical words named in Phase 3. Note that there were two lists of target/competitor pairs (allergy/analogy and liberty/library) and assignment of list to condition was fully counterbalanced. For clarity the figure shows a single counterbalance condition.

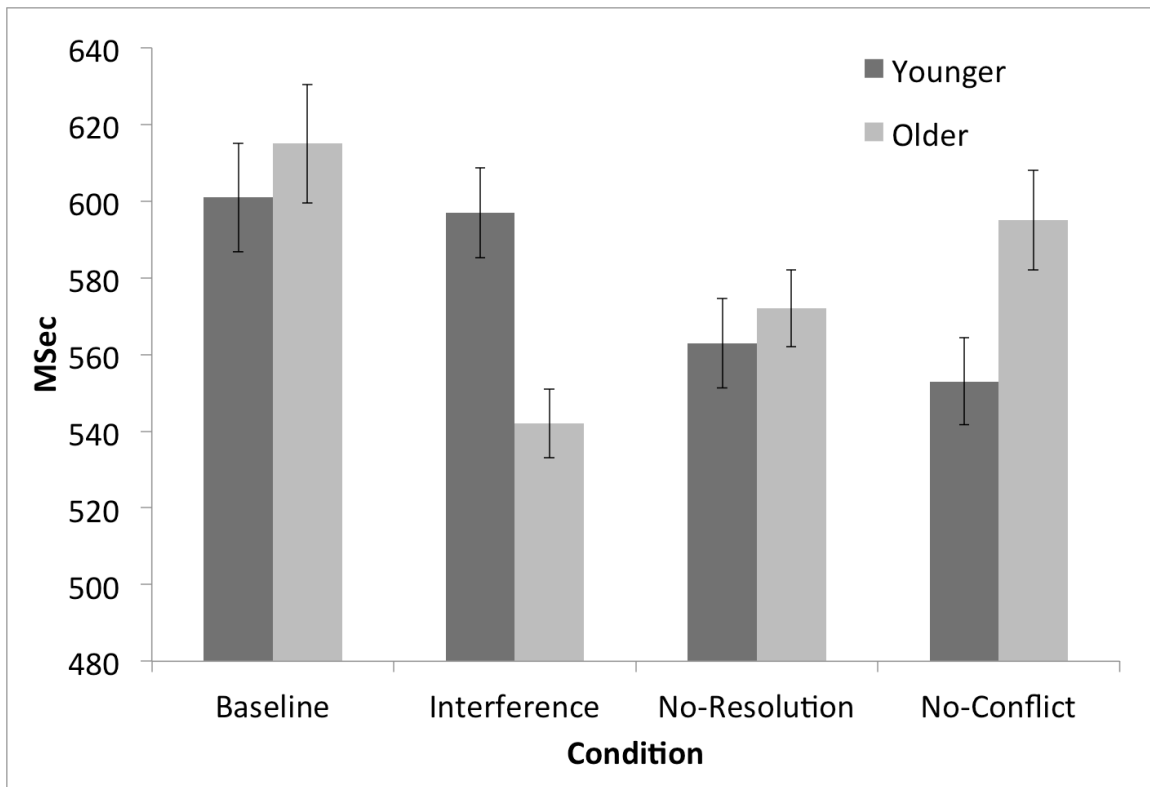


Figure 2. Mean naming times for competitor words by condition in the Phase 3 naming time task for older versus younger adults. Error bars represent one standard error of the mean, note that because our analyses control for new word naming time, the significance of mean differences cannot be inferred directly from the standard errors. Younger adult data are from Healey et al. (2010). Note that a 15% Winsorizing procedure was used for both the younger and older adult data reported here, and thus the younger adult means differ slightly from those reported in Healey et al. (2010) where 5% Winsorizing was used.

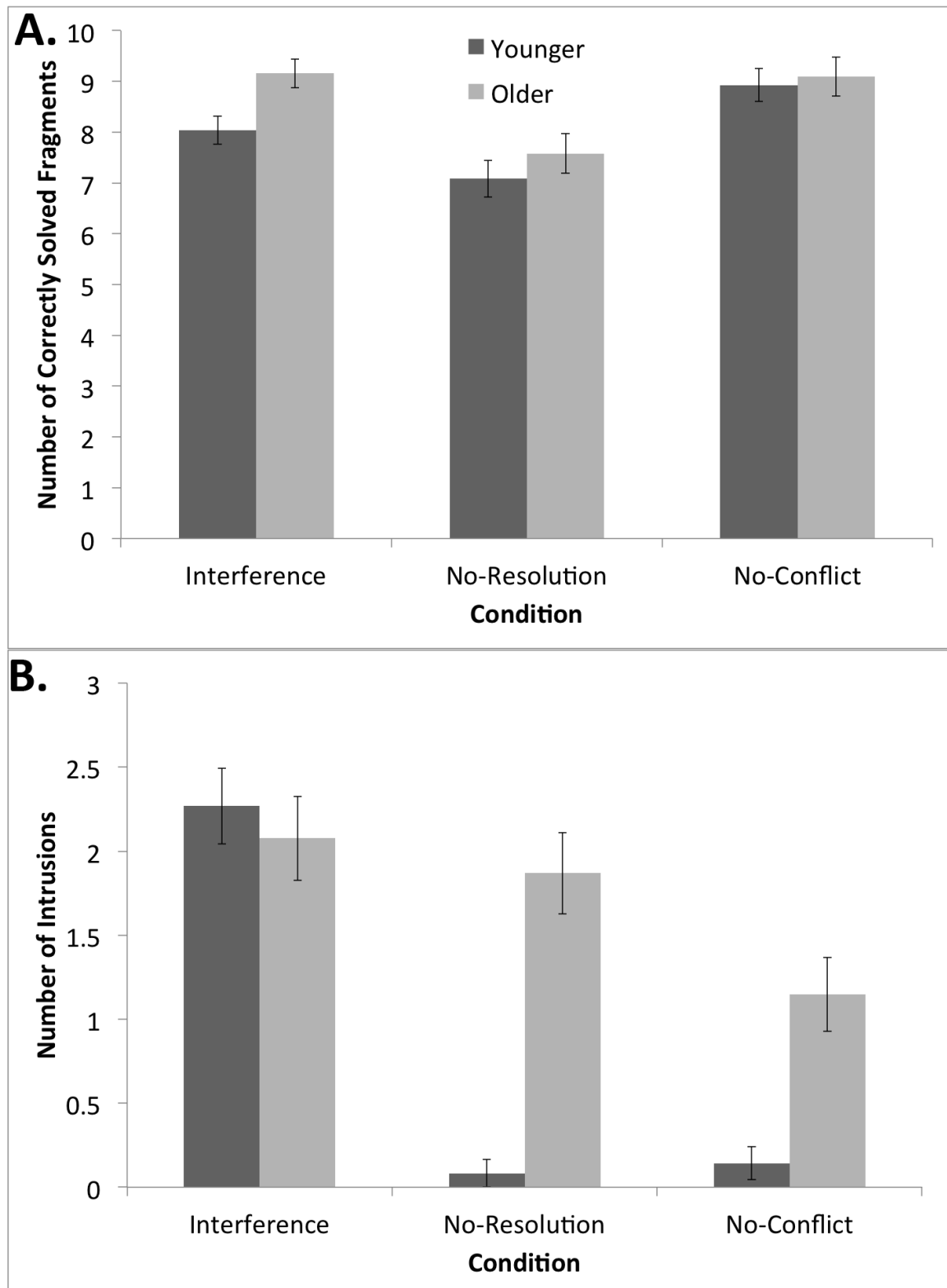


Figure 3. A. Mean number of fragments correctly solved. B. Mean competitor intrusion rates for critical fragments. Error bars represent one standard error of the mean.