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

M. Karl Healey
University of Toronto,
The Rotman Research Institute, Baycrest Centre,
and the University of Pennsylvania

W. Joan Ngo
University of Toronto

Lynn Hasher
University of Toronto and The Rotman Research Institute,
Baycrest Centre

Resolving interference from competing memories is a critical factor in efficient memory retrieval, and difficulty resolving interference may underlie memory deficits such as those seen in the elderly. Many researchers have suggested that the ability to suppress competitors is a key factor in resolving interference, but the evidence supporting this claim has been the subject of considerable debate. Here we present a new paradigm that provides evidence 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, supporting the theory that older adults' memory deficits are related to impaired suppression.

We and others have argued that selecting among competing memories during retrieval entails suppressing the competitors based 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. 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 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 Operation Span (OSpan), a well–validated measure of memory (Conway et al., 2005).

In a second experiment we replicate the below–baseline suppression effect with a new sample of young adults, and test 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, 2002; Winocur & Moscovitch, 1983) and several 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). Replicating the results of Experiment 1 and, as predicted by inhibitory theory, older adults showed no evidence of suppressing competitors.

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phone: (215) 746–3500
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Experiment 1

Method

Overview

The first task, word generation, presented a long list of cue words. A task instruction was presented 250ms after the appearance of each cue word. For some cues the instruction signaled participants to produce a strong associate of the cue (Related trials), for other cues the instruction signaled them to produce a weak associate of the cue (Unrelated trials). Because visually presented words automatically activate their meaning within 250ms (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 strong associates would be activated in both conditions but the initial activation would have to be suppressed in the Unrelated condition in order to produce an appropriate response. To test if the strong associates were indeed suppressed, a second task, speeded word naming, was used to measure their accessibility. The list for the word naming task included the closest associates (or, target words) of the cue words from the generation task along with control items that were unrelated to any previously presented words. If selecting a weak associate involves suppressing strong associates, participants should be slower to name the target words from Unrelated trials than from Related trials and Control words.

Participants

Fifty–two university students (mean age = $19.73, SD$ = 2.54) who were native English speakers participated for course credit.

Stimuli

Sixty cue–target pairs (e.g., HIVE–BEE) were selected to have high cue–to–target associations but weaker target–to–cue (backward) associations. Three 20–pair lists were created and assigned to the Related, Unrelated, and Control conditions in a fully counterbalanced fashion. See Supplementary Table 1 for the pairs. To create the pairs, we began with all of 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 0.5 and target–to–cue associations greater than 0.2. We eliminated items with frequencies more than 3 *SD*s from the mean of surviving items. The resulting 60 pairs were divided into three 20–pair lists. We equated the lists on forward and backward association strength, word length, word frequency, normed naming time, *SD* 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, concreteness, word length, and mean naming time, and nearly so for the others. For each participant the three lists were randomly assigned to one of the three conditions, with list–condition assignments being counterbalanced across participants.

Procedure

During the generation task, each cue word was presented alone for 250ms, after which a task instruction (Related or Unrelated) appeared above the word. For Related trials, participants were instructed to say âĂIJthe first word that comes to mind that is meaningfully related or strongly associated to the cue wordâĂİ. For Unrelated trials, they were instructed to produce a word âĂIJthat has as little relationship with the cue word as possibleâĂİ. Cue words remained onscreen until a response was given, followed by a 1,500ms ISI. Twenty trials of each type were randomly intermixed. Within each 10–trial block of the generation task, there were 5 related and 5 unrelated items 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.

During the naming task, participants read each of a series of words as quickly as possible. The list included the associated target words of the Related and Unrelated cue words along with 100 fillers. Words were presented until a response was given, followed by a 1,500–ms ISI. The naming test began with 8 filler items. Remaining items were divided into 4 blocks. Within each block, 5 related, 5 unrelated, 5 control, and 23 filler items were presented in random order with the constraint that no more than 2 critical items (related or unrelated) appeared consecutively. We used Latent Semantic Analysis (Landauer & Dumais, 1997) to ensure the filler words were not strongly related to any cues or targets.

Participants then completed OSpan. Each OSpan trial (the version described in Conway et al., 2005) presents 2–5 words, each preceded by a simple math equation, which the participants must verify. At the end of each trial, participants attempt to recall the words in serial order.

Data Processing

Differences in mean reaction times across conditions are quite sensitive to even a small number of fast or slow outlying responses (Ratcliff, 1979), therefore we employ a trimming scheme designed to reduce the influence of such outlying responses 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 reaction times faster than 200 ms or slower than 2000 ms (these two cutoffs resulted in excluding 0.56% and 0.29% of responses respectively). After excluding these extreme values, any remaining values more than 2.5 *SDs* from the mean were replaced with a value equal to the mean ±2.5 *SDs* (impacting an average of 0.23% of responses per participant). Therefore the total trimming rate was approximately 1% of responses, well below the 5%–15% trim 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 word, participants should subsequently be slowed to name it. In the Related condition participants were not required to reject the targets and therefore, target naming should show no slowing. Slowing can be assessed against naming time for counterbalanced Control words, which were unrelated to any cues from the generation list . Figure 1A shows the means and 95% within–subject confidence intervals. The critical question is whether naming was slowed for the associated target words in the Unrelated condition. As can be seen from the non–overlapping confidence intervals, naming of Unrelated targets was indeed slower than naming of either Control words or Related targets, evidence that selecting a cue's weak associates involved suppressing its strong associates.

In most suppression paradigms competitors are primed prior to interference resolution and suppression reduces that priming (Anderson & Green, 2001; Anderson & Spellman, 1995; Blaxton & Neely, 1983; Healey et al., 2010; Higgins & Johnson, 2009; Radvansky, Zacks, & Hasher, 2005; Storm, 2011). That is, while competitors are less accessible than Control items, their net accessibility generally increases from the beginning of the experiment to the end. Here we observe a net decrease of competitor accessibility. Thus, the results constitute some of the strongest evidence available for the role of suppression in retrieval.

If the slowing effect reported above does indeed reflect the resolution of memory interference then individuals who show more slowing, and thus stronger suppression, should preform well on memory tasks. To test this prediction, we correlate individual differences in the slowing effect with performance on OSpan, a memory task known to be vulnerable to interference (Bunting, 2006; May, Hasher, & Kane, 1999; Rowe, Hasher, & Turcotte, 2008). This analysis also allows us to test an alternative account of the slowing effect.

Episodic Blocking

An alternative explanation should be considered before attributing slowing in the Unrelated condition to suppression. During each trial of the 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 is HIVE, a participant on an Unrelated trial may initially think of the strong associate BEE but eventually produce 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 naming time task, it would trigger retrieval of both HIVE and CHAIR via these new episodic associations, and the time taken for this episodic retrieval to occur would slow naming. That is, new episodic associations may âĂIJblockâĂİ access to the target word. Similar blocking accounts have been a key criticism of other suppression paradigms (e.g., Tomlinson, Huber, Rieth, & Davelaar, 2009). We can take advantage of the fact that episodic retrieval should occur in both the Related and Unrelated conditions to test the blocking account by computing separate blocking and suppressions scores for each participant.

Specifically, an individual's RT in the Unrelated condition reflects their baseline word naming speed plus any effect of suppression plus any effect of blocking.

$$UnrelatedRT = baseline + blocking + suppression \tag{1}$$

However, unlike suppression, which should occur only in the Unrelated condition, blocking should occur in both the Unrelated and the Related condition.

$$RelatedRT = baseline + blocking \tag{2}$$

Thus we can create a suppression score as a simple difference between RTs in the Unrelated and Related conditions.

$$suppression = UnrelatedRT - RelatedRT \tag{3}$$

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

$$blocking = RelatedRT - ControlRT \tag{4}$$

Note that while we used difference scores for explanatory purposes, difference scores do not remove the between–individual variability associated with the subtracted term, it just reverses the sign of that variability. Therefore the actual suppression and blocking scores used in the analyses reported below were residuals from regressions following the equations outlined above. Specifically for the suppression score we used residuals from the regression:

$$UnrelatedRT = \beta_0 + \beta_1 RelatedRT \tag{5}$$

For the blocking score we used residuals from the regression:

$$RelatedRT = \beta_0 + \beta_1 ControlRT \tag{6}$$

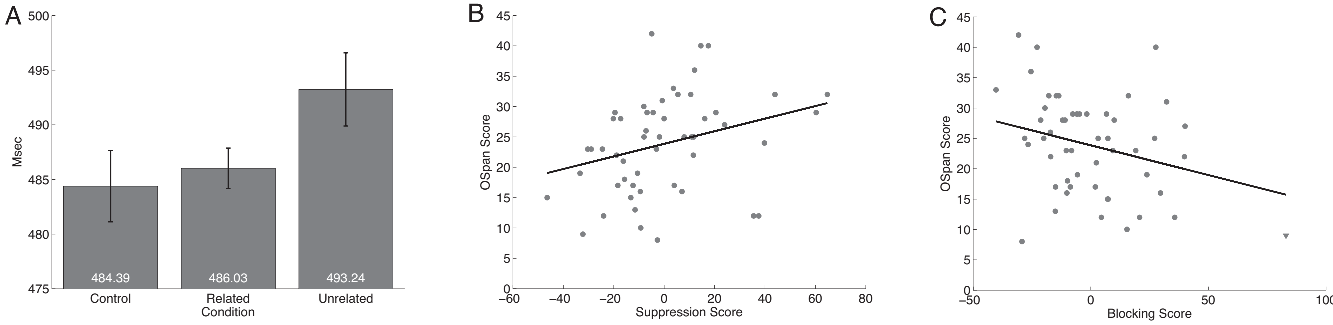

Figure 1. **A.** Mean naming time by condition for critical items in the naming task of Experiment 1. Error bars are 95% confidence intervals calculated using the Loftus and Masson (1994) method for within–subject designs. The means of conditions with non–overlapping error bars are significantly different at the α = .05 level. The Unrelated condition is significantly slower than the Control and Related conditions, which do not differ from each other. **B.** Scatter plot of suppression scores versus Operation Span scores. The line is a least squares regression line. **C.** Scatter plot of blocking scores versus Operation Span scores. The line is a least squares regression line. The triangular data point in the lower right corner is a likely outlier and was removed from the final analyses reported in the text.

We can then use the suppression and blocking scores to address a blocking account of the slowing effect. Under the blocking account, slowing in the Unrelated condition occurs because participants fail to control interference from Phase 1 during the naming time test, and thus slowing should not correlate positively with memory performance on Operation Span because the slowing reflects a failure of interference regulation during the initial word production task. Under the suppression account, by contrast, slowing occurs because participants succeed in reducing interference by suppressing the activation of the strong associate, and thus individuals who show more suppression should perform better on memory tasks that, like operation span, require controlling interference.

To test the blocking account we correlated Operation Span scores with suppression and blocking scores. As expected, the correlation for suppression scores was positive, $r(50) = .33, p = .016$ (Figure 1B). That is, suppression is associated with better span scores. For the blocking account to remain viable in light of this positive correlation, it must make the implausible prediction that blocking scores are also positively correlated with span. Contrary to this prediction, the correlation was actually negative, $r(50) = -.33, p = .016$. Inspection of the scatterplot in Figure 1C reveals a particularly influential observation in the lower right corner. When this observation is eliminated the correlation remains negative but is no longer significant, $r(49) = -.24, p = .086$, and certainly not positive as predicted by the blocking account[1] . For a similar finding see Aslan and Bäuml (2011).

Experiment 2

In Experiment 2 we test both young and older adults on the paradigm developed in Experiment 1. Doing so provides the opportunity to replicate the finding of below baseline suppression in younger adults and to achieve two additional goals. First, a replication will provide additional support for a suppression interpretation of the slowing effect observed in Experiment 1. If the slowing effect is due to interference during the naming time test (e.g., blocking) rather than suppression, older adults should show more suppression 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, 2002; Winocur & Moscovitch, 1983). Second, it allows 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, they should show less slowing than younger adults.

Method

Seventy older adults age 60–77 (mean = 66.91, *SD* = 4.50) and 38 younger adults age 17–34 (mean = 20.74 *SD* = 3.71) participated. Older adults had an average of 16.8 (*SD* = 3.44) years of education and scored 36.84 (*SD* = 2.50) on the (Shipley, 1946) vocabulary test compared to an average of 14.04 (*SD* = 1.70) years of education and average Shipley score of 31.42 (*SD* = 3.87) for younger adults (both the education and vocabulary age differences were significant, as is common in the aging literature). All other aspects of the method and data screening were identical to Experiment 1. On average, data trimming impacted 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, $F(2, 212) = 3.30, p = .039$. Replicating Experiment 1, younger adults showed below–baseline suppression of associates from the Unrelated trials; target naming was slower for Unrelated items than for either Control items or Related items (see confidence intervals in Figure 2). By contrast, older adults showed no evidence of suppression: there was no effect of condition for older adults $F(2, 138) = 0.52, p = .59$. Pairwise comparisons confirmed that, for older adults, the unrelated condition did not differ from either Control or Related RTs, $t's < 1$. 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.

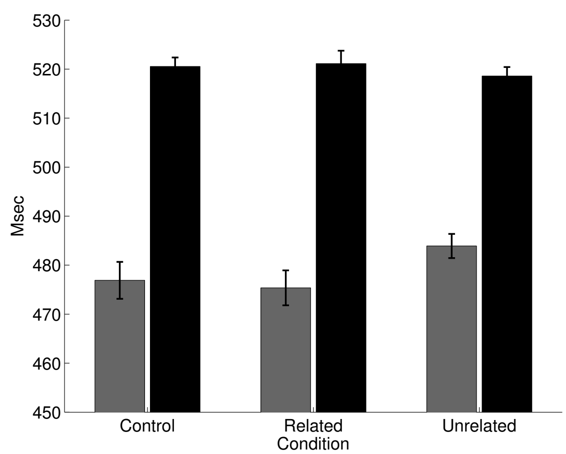

Figure 2. Mean naming time by condition and age group for critical items in the naming task of Experiment 2. Error bars are 95% confidence intervals calculated using the Loftus and Masson (1994) method for within–subject designs. The means of conditions with non–overlapping error bars are significantly different at the $\alpha = .05$ level.

General Discussion

Interference resolution is a critical factor in a healthy memory system. We provide 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 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.

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

References

Anderson, M. C., & Green, C. (2001). Suppressing unwanted memories by executive control. *Science*, *410*, 366 - 369.

Anderson, M. C., Reinholz, J., Kuhl, B. A., & Mayr, U. (2011). Intentional suppression of unwanted memories grows more difficult as we age. *Psychology and Aging*.

Anderson, M. C., & Spellman, B. A. (1995). On the status of inhibitory mechanisms in cognition: Memory retrieval as a model case. *Psychological Review*, *102*, 68-100.

Aslan, A., & Bäuml, K.-H. T. (2011). Individual differences in working memory capacity predict retrieval-induced forgetting. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*(1), 264–269.

Balota, D. A., Yap, M. J., Cortese, M. J., Hutchison, K. A., Kessler, B., Loftis, B., ... Treiman, R. (2007). The English Lexicon Project. *Behavior Research Methods*, *39*(3), 445–459.

Blaxton, T. A., & Neely, J. N. (1983). Inhibition from semantically related primes: Evidence of a category-specific inhibition. *Memory and Cognition*, *11*(5), 500–510.

Bunting, M. (2006). Proactive interference and item similarity in working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *32*(2), 183–196.

Campbell, K. L., Hasher, L., & Thomas, R. C. (2010). Hyperbinding: A unique age effect. *Psychological Science*, *21*(3), 399–405.

Conway, A. R. A., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review*, *12*(5), 769–786.

Gazzaley, A., Cooney, J. W., Rissman, J., & D'Esposito, M. (2005). Top-down suppression deficit underlies working memory impairment in normal aging. *Nature Neuroscience*, *8*(10), 1298–1300.

Hasher, L., Lustig, C., & Zacks, R. T. (2007). Inhibitory mechanisms and the control of attention. In A. Conway, C. Jarrold, M. Kane, A. Miyake, & J. Towse (Eds.), *Variation in working memory* (pp. 227–249). New York: Oxford University Press.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances* *in research and theory* (p. 193-225). San Diego: Academic Press.

Hasher, L., Zacks, R. T., & May, C. P. (1999). Inhibitory control, circadian arousal, and age. *Attention and Performance*, *17*, 653–675.

Healey, M. K., Campbell, K. L., Hasher, L., & Ossher, L. (2010, October). Direct evidence for the role of inhibition in resolving interference in memory. *Psychological science*, *21*(10), 1464–1470.

Healey, M. K., Hasher, L., & Campbell, K. L. (in press). The role of suppression in resolving interference: Evidence for an age-related deficit. *Psychology and Aging*.

Higgins, J. A., & Johnson, M. K. (2009). The consequence of refreshing for access to nonselected items in young and older adults. *Memory and Cognition*, *37*(2), 164–174.

Hulicka, I. (1967). Age differences in retention as a function of interference. *Journals of Gerontology*, *22*(2), 180–184.

Ikier, S., & Hasher, L. (2006). Age differences in implicit interference. *The Journals of Gerontology*, *61b*, 278–284.

Ikier, S., Yang, L., & Hasher, L. (2008). Implicit proactive interference, age, and automatic versus controlled retrieval strategies. *Psychological Science*, *19*(5), 456–461.

Kane, M. J., & Hasher, L. (2002). Interference. In G. Maddox (Ed.), *Encyclopedia of aging* (pp. 514–516).

Landauer, T. K., & Dumais, S. T. (1997). A solution to Plato's problem: The latent semantic analysis theory of acquisition, induction, and representation of knowledge. *Psychological Review*, *104*, 211-240.

Loftus, G. R., & Masson, M. E. J. (1994). Using confidence intervals in within-subject designs. *Psychonomic Bulletin & Review*, *1*, 476-490.

May, C. P., Hasher, L., & Kane, M. J. (1999). The role of interference in memory span. *Memory & Cognition*, *27*, 759–767.

Neely, J. H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. *Journal of Experimental Psychology: General*, *106*(3), 226–254.

Nelson, D. L., McEvoy, C. L., & Schreiber, T. A. (1998). The university of south florida word association, rhyme, and word fragment norms. *http://w3.usf.edu/FreeAssociation/*.

Norman, K. A., Newman, E. L., & Detre, G. (2007). A neural network model of retrieval-induced forgetting. *Psychological Review*, *114*(4).

Ortega, A., Gómez-Ariza, C. J., Román, P., & Bajo, M. T. (2012). Memory inhibition, aging, and the executive deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *38*(1), 178–186.

Rabovsky, M., Sommer, W., & Abdel Rahman, R. (2012). The time course of semantic richness effects in visual word recognition. *Frontiers in human neuroscience*, *6*, 1–9.

Radvansky, G., Zacks, R., & Hasher, L. (2005, January). Age and inhibition: The retrieval of situation models. *Journals Of Gerontology*, *60B*(5), P276–P278.

Ratcliff, R. (1979). Group reaction time distributions and an analysis of distribution statistics. *Psychological Bulletin*, *86*(3), 446–461.

Ratcliff, R. (1993). Methods for dealing with reaction time outliers. *Psychological Bulletin*, *114*(3), 510–532.

Rowe, G., Hasher, L., & Turcotte, J. (2008). Age differences in visuospatial working memory. *Psychology and Aging*, *23*(1), 79–84.

Shipley, W. C. (1946). *Shipley institute of living scale*. Los Angeles, CA: Western Psychological Services.

Storm, B. (2011). The benefit of forgetting in thinking and remembering. *Current Directions in Psychological Science*, *20*(5), 291–295.

Tomlinson, T. D., Huber, D. E., Rieth, C. A., & Davelaar, E. J. (2009, January). An interference account of cue-independent forgetting in the no-think paradigm. *Proceedings of the National Academy of Sciences, USA*, *106*(37), 15588–15593.

Winocur, G., & Moscovitch, M. (1983). Paired-associate learning in institutionalized and noninstitutionalized old people: An analysis of interference and context effects. *Journals of Gerontology*, *38*(4), 455–464.